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STRAIN GAUGE STANDARD VDI/VDE 2635; BONDED ELECTRIC RESISTANCE STRAIN GAUGES, CHARACTERISTICS AND TESTING CONDITIONS

Translation of "Dehnungsmessstreifen mit metallischem Messgitter VDI/VDE 2635; Kenngrössen und Prüfbedingungen". Verein Deutscher Ingenieure/Verband Deutscher Elektrotechniker, Dusseldorf, 1974, pp. 1 - 31.

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16. Abstract

This guideline contains the definition of strain gauge parameters and how they are to be determined, as well as how measurements are to be taken and presented. The guideline was prepared by the "experimental stress analysis" panel of the German Engineer's Association.

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P R E F A C E

Products of various manufacturers can only be compared if their parameters are determined under the same conditions and with the same purpose. This led the VDI/VDE panel on "Experimental Stress Analysis" to develop guidelines for the definition and determination of parameters of strain gauge strips containing metallic grids. Also measurement results are presented.

Foreign papers were used [1 to 5] and contact was made with foreign organizations. The already existing specifications [1, 3, 5] were taken over if it was technically justified. Otherwise they were changed or extended. The deviations are quite considerable, so that the testing according to one of the mentioned specifications is not at all equivalent with tests carried out according to the present guidelines. An attempt was made to extend the information content of the test results towards the application of strain gauges to various problems. The panel considers the present directives as a contribution to a future international agreement.

The guideline contains the definition of the parameters, describes methods for determining them (measurement conditions) and specifies the way in which the measurement results are to be represented and published. At the present time it is not yet possible to classify strain gauges into classes according to their application. The application classes will be included in the guidelines at a later time.

The guidelines were prepared within the framework of the "experimental stress analysis" panel (director: Prof. Dr.-Ing. R. K. Müller, Stuttgart) with the support of the panel members

Obering, K. Hoffmann, Darmstadt and Prof. Dipl.-Phys. N. Czaika, Berlin.

Association of German Engineers
Association of German Electrical Technicians.

TABLE OF CONTENTS

STRAIN GAUGE STANDARD VDI/VDE 2635;
BONDED ELECTRIC RESISTANCE STRAIN GAUGES,
CHARACTERISTICS AND TESTING CONDITIONS

Verein Deutscher Ingenieure,
Verband Deutscher Elektrotechniker /2*

1. GENERAL REMARKS

1.1. Introduction

This guideline refers to strain gauges with included metallic measurement grids. In the following we will use the abbreviation "DMS" in the text. It is the purpose of this guideline to define the most important characteristics of strain gauges and to describe a method for determining them, including the test conditions. In this way we wish to bring about a correct selection procedure for strain gauges and to make it possible to give an evaluation of the products of various manufacturers*.

The methods presented will make it possible to allow anyone to obtain comparable results using the mentioned installations and provided he has the requisite experience.

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* Numbers in margin indicate pagination in original foreign text.

** In this guideline, all firms are producers which sell strain gauges and adhesives. These are manufacturers, importers and dealers.

The testing of the strain gauges, according to this guideline and the publication of results (see Section 1.7), allows the dealers to use the notation "tested according to the VDI/VDE guideline 2635". If only one part of the offered strain gauge program is tested, the strain gauge types or strain gauge families must be clearly specified.

1.2. Testing of measurement installations

The installations and instruments for determining strain gauge characteristics according to this guideline must be calibrated initially and at regular intervals.

One necessary condition for using the notation "tested according to the VDI/VDE guideline 2635" is a one-time testing of the installation by an official institution (in Germany, for example, the Physical-Technical Federal Association (PTB) in Braunschweig, the Federal Institute for Material Testing (BAM) in Berlin or the federal material test facility in the individual states).

1.3. Concept definition for the test object

1.3.1. Strain gauge application

Most properties of a strain gauge can only be measured after it has been applied. Because of the adhesive, the method of attachment, the leads, and the covering material, the material of the test piece can influence the strain gauge properties. The test object in the sense of this guideline is the strain gauge which has been applied and which is ready for measurement. The investigation project defined in this way is called "strain gauge application". Accordingly, in addition to the "general specifications" for strain gauges given in Table 1, in order to give a unique characterization of a strain gauge application, it is necessary to mention the adhesive used in the test and the attachment method, possibly also the covering material and the material of the work piece. If a strain gauge supplier recommends several adhesives for a strain gauge or a family of strain gauges, it must be specified which combination was used to produce the results. If an adhesive can be used in several application methods (for example, various hardness programs for the same adhesive), then it is sufficient to determine the data for one program selected by the supplier. The method used must be described in detail or reference must be made to a readily available application directive, which sometimes is supplied with the adhesive. /3

1.3.2. Strain gauge lot

All strain gauges which are produced during a continuous fabrication process under the same conditions and with the same initial material are part of the same strain gauge lot (manufacturing lot).

In addition, it is necessary that the measurement grid material is produced from the same melt and that it has experienced the same mechanical and thermal treatment. Strain gauges in which the measurement grid comes from the same melt, but for which the subsequent processing is done according to individual different methods, cannot be assigned to the same strain gauge lot, even if the subsequent processing was done according to the same specifications.

1.3.3. Strain gauge type

The concept "type" refers to strain gauges which have the same shape, dimensions, material and manufacturing method. They can come from various lots.

1.3.4. Strain gauge family

By a strain gauge family we mean a continuous series of strain gauge types. The types of the strain gauge family must have the same material in all components and the production method must be the same. The dimensions of the various types must be staggered in such a fashion that it is possible to estimate the behavior of the other types of the strain gauge family from the data given in Section 1.4b.

1.3.5. Test pieces

As a rule, rods, plates and other bodies are used as test pieces. Strain gauges are applied to them and the properties are determined.

1.3.6. Static measurement

The concept of a "static measurement" refers to the strain gauge technology involving all measurements of strains or strain components which are constant in time. For example, a process which is constant in time is used also when another oscillation component is superimposed.

1.3.7. Dynamic measurement

All measurements involving varying strain processes in which only the dynamic component is determined are called

TABLE I. CHARACTERISTICS AND PARAMETERS OF STRAIN GAUGES

1	2	3	4	5
Characteristic, parameter	Section number	Indications in each package	Indications in data sheets	Testing only after previous agreement
<u>Characteristics to be specified</u>	2.			
Type	2.1	+	+	
Manufacturing sample	2.2	+		
Strain gauge structure	2.3		+	
Dimensions	2.4		+	
Adhesives used	2.5		+	
Application method for adhesives	2.6		+	
Number of parts per package	2.7	+	+	
<u>Parameters to be tested</u>	3.			
Strain sensitivity (k factor) at room temperature	3.1	+	N[2])	
Linearity error at room temperature	3.3		+	
Mechanical hysteresis at room temperature	3.2		+	
Maximum strain at room temperature	3.4		+	
Resistance at room temperature	3.5	+	N	
Maximum electrical load at room temperature	3.6		+	
Smallest radius of curvature at room temperature	3.7		+	
Restoring force per strain of strain gauge at room temperature	3.8		+	
Transverse sensitivity at room temperature	3.9		+	
Temperature variation	3.10	+	N	
Thermal hysteresis	3.11			+
Temperature resistance	3.12			+

TABLE I (CONTINUED):

1	2	3	4	5
Characteristic, parameter	Section number	Indications in each package	Indications in data sheets	Testing only after previous agreement
Thermal voltage between measurement grid materials, connection materials and lead materials.	3.13		+	
Temperature dependence of the k factor (static)	3.14	+		
Maximum strain as a function of temperature	3.15			+
Maximum strain as a function of humidity at room temperature.	3.16			+
Heat shock behavior	3.17			
Drift as a function of temperature.	3.18		+	
Continuous oscillation behavior at room temperature	3.19			+
Creep as a function of temperature	3.20		+	
Drift as a function of relative humidity at room temperature	3.21			+

2) N characteristics and parameters, respectively.

dynamic measurements. For example, we have the amplitude of an oscillation.

1.3.8. The measurement unit of strain

The strain ε is the quotient of a reference length L_o and its change ΔL(DIN 1350):

$$\epsilon = \frac{\Delta L}{L_0} \tag{1}$$

/4

It has the unit $\frac{m}{m}$. When a fraction is eliminated, an unknown number results. However, the physical information regarding the origin of the measure is lost so that errors can occur especially in conjunction with other ratios [6-8]. On the other hand, several pseudo units are used in everyday practice, but these only contribute to the confusion and primarily contradict the calculation of magnitudes.

In agreement with the Standards and Formula Board (AEF) of the German Standard Board, we suggest the following rule:

The strain is to be indicated as a product of numerical value and the unit m/m. Since strains as a rule are very small ratios, the numerical value should be written as a power of ten. For example,

$$\epsilon_1 = 180 \cdot 10^{-6} \frac{m}{m},$$
$$\epsilon_2 = 2{,}5 \cdot 10^{-3} \frac{m}{m},$$
$$\epsilon_3 = 3 \cdot 10^{-2} \frac{m}{m}.$$

The powers 10^{-6}, 10^{-3} and 10^{-2} are recommended.

The decade short notation according to DIN 1301 can be used instead of the powers- that is, as follows for the preceding example

$$\begin{aligned} \epsilon_1 &= 180\ \mu m/m, \\ \epsilon_2 &= 2{,}5\ mm/m, \\ \epsilon_3 &= 3\ cm/m. \end{aligned}$$

This notation facilitates typing. The notations % (percent) and ‰ (promille) are to be avoided for strain indications, in all cases, because they can lead to confusion with tolerance indications. They are permissible as tolerance notations, for example

$$\epsilon = x \cdot 10^{-n}\ \frac{m}{m} \pm p\%.$$

1.4. Extent of the testing

The number of strain gauge properties which could be tested is so large that certain restrictions are required because of the costs involved.

a) It is sufficient to include the data and indications with each strain gauge package. As a minimum one must specify the data given by a cross in column three of column 1. This information must be given by the manufacturer.

b) The characteristics given in column 4 of Table 1 should be determined for a strain gauge type with an active measurement grid length of at least 6 mm, provided the individual descriptions in sections two and three do not require additional data. It must be specified whether or not strain gauges are used with variable measurement grid lengths.

The results of these measurements are characteristic for the entire strain gauge family and should make it possible to compare various strain gauge families. It cannot be assumed that they are valid for other types of the strain gauge family.

The publication of such "characteristic" data and the specification should therefore conform in a suitable way to this rule, for example, in technical data sheets. The manufacturer is expected to give the requested information.

c) This guideline mentions in column 5 of Table 1 a number of additional strain gauge properties and indicates test methods for them. The determination of this data is subject to an agreement between the user of a strain gauge and the producer or test facility. Measurements which go beyond the scope of section b), for example, testing with special strain gauge types, are also included here.

d) The number of strain gauge properties which can be tested could even be enlarged. We did not extend the list, because either there were no tested test methods or the boundary conditions were too special in order to develop and justify a generally valid testing method (see section 3.17). The insulation resistance was not included in the guideline because it is only important because of its effect on other characteristic parameters.

1.5. Measurement methods to be generally used and measurement conditions to be maintained

1.5.1. Measurement of the relative resistance change

The electrical devices for determining the relative resistance change $\Delta R/R_0$ of the strain gauges cannot have an error greater than ±0.1% or $\pm 5\,\mu\Omega/\Omega$. This should include all of the error sources, such as connection lines, circuits, circuit elements and similar items. The error is to be controlled using a resistance standard instead of the strain gauge being tested. The resistance standard should have a total range of $20000\,\mu\Omega/\Omega$

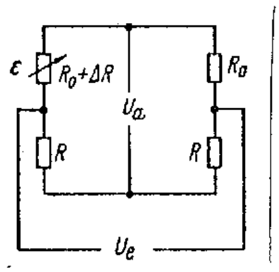

Figure 1. Wheatstone bridge with active strain gauge (four bridge circuit).

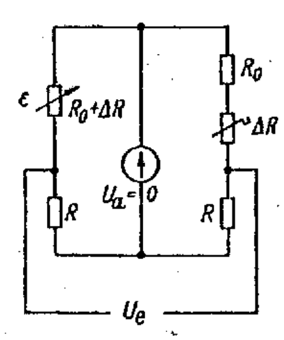

Figure 2. Compensation of the resistance change of the strain gauge for avoidance of linearity errors from the bridge circuit.

which has coarse divisions of 2,000 and fine divisions of $200\,\mu\,\Omega/\Omega$. The errors cannot be greater than 0.05% in the fine divisions and 0.02% in the coarse divisions and in the overall sum.

If necessary, linearity errors of the bridge circuit are to be excluded by appropriate measures, for example, by compensating the resistance change of the tested strain gauge using measurable resistance changes in the adjacent branch of a symmetric Wheatstone bridge. /5

Remarks:

In usual Wheatstone bridge circuits, Figure 1 (quarter-bridge), the resulting linearity errors are much too large, especially in the range of large strain.

Since for small strains we have

$$\frac{U_a}{U_e}=\frac{1}{4}\cdot\frac{\Delta R}{R_0}\sim\epsilon. \qquad (2)$$

and for large strains we find

$$\frac{U_a}{U_e} = \frac{\Delta R}{4R_0 + 2\Delta R} \sim \varepsilon. \tag{3}$$

If the strain is determined in the usual manner according to Equation (2), the error is

$$f_{rel} = \frac{-\Delta R}{2R_0 + \Delta R} \cdot 100\% \tag{4}$$

The convenient way of avoiding linearity errors is shown in Figure 2. The resistance change of the strain gauge is compensated by a decade resistance of high accuracy. The galvanometer is used as a zero instrument. ΔR is read off directly on the decade resistance.

U_a - bridge output voltage,

U_e - bridge input voltage.

When alternating voltage is used for measurements, the inductive or capacitive influences are not allowed to increase the error.

The resistance of the strain gauge attached to the sample is the reference resistance R_0 of a strain gauge. It cannot change at room temperature by more than 0.2% from the resistance it had when it was delivered.

1.5.2. Temperature measurement

The devices and sensors used for temperature measurements should have a resolution of 1° C with an uncertainty of $\leq 2°C$, unless other tolerances are specified.

1.5.3. Measurement current

The current flowing through a strain gauge during a measurement can influence its properties. It is not possible to standardize the measurement current because of the multiplicity of the measurement instruments. When time dependence and other properties are measured, multi-point techniques will be used and the strain gauge is connected only for a short time during the measurement recording to the voltage supply. Therefore, it is necessary to indicate the magnitude of the measurement current and the duration over which it is turned on, together with the measurement results.

1.5.4. Room temperature and conditioning

Measurements carried out "at room temperature" should be carried out in an environment of (23 ± 2) °C and (50 ± 3)% relative humidity (normal climate 23/50 according to DIN 50014).

1.5.5. Climate at higher and lower temperatures

If nothing else is specified, at temperatures above 23° C, a constant absolute humidity of 10.3 g H_2O per m^3 is to be used for air at a pressure of 1 bar, corresponding to a relative humidity of 50% at 23° C or a partial pressure of 13.5 mbar. This case, for example, can be realized using a thermostat, the outer chamber of which is connected with the outside atmosphere 23/50. At temperatures below 23° C, 50% relative humidity is desirable. In no case can humidity be allowed to be deposited on the sample.

1.5.6. Storage of the samples before the measurement

The humidity in the air affects the quality of the adhesive connection as well as the properties of the applied strain gauge [9]. Therefore, strain gauges to be tested are to be stored for 72 hours in a normal climate 23/50 according to DIN 50014. If the strain gauges are heated during application, an additional 72 hour storage in the normal climate 23/50 is required. This procedure is not to be used in section 3.10.

The air must have unobstructed access to the strain gauge or to the application point.

Deviations from this requirement are not permissible if the attachment method requires a different procedure, for example, a covering of the strain gauge. In this case the instructions given by the manufacturer apply. It is to be published together with the measurement results.

Remarks:

One must assume that by using covering devices, for example for humidity protection or mechanical effects, the properties of a strain gauge application can change.

1.6. Sampling and evaluation

This guideline requires the following test methods for various strain gauge properties:

- a_1) Sample testing (section 3.5),
- a_2) Continuous random sampling testing (section 3.1 and 3.10),
- a_3) Type testing (all other sections).

The testing of the properties referred to under a_2 and a_3 can only be done with applied strain gauges. Since these can no longer be used for sale or reuse, the tests must be carried out with samples.

b) For sample tests, the tolerance is either to be specified in units of the measurement quantity or in percent of the average value.

e) For random sample tests it is assumed that the static quality control applies and that the variable tested is normally distributed. The random sample must be taken from a single manufacturing lot.

/ 6

The extent of the random sample determines the information content of the results. It must be given in all cases. As a minimum for a random sample, n = 5 pieces must be used. For tests in which a random sample is distributed over both sides of the test body (see section 3.1), a minimum of n = 6 pieces must be used. (See also DIN 1319 and DIN 55302).

d) From the measurement data x_1 to x_n of the strain gauges 1 to n, one calculates the arithmetic mean $\bar{x}$ according to equation

$$\bar{x} = \frac{1}{n} \sum_{i=1}^{n} x_i \qquad (5)$$

and the standard deviation according to equation

$$s = \sqrt{\frac{1}{n-1} \sum_{i=1}^{n} (x_i - \bar{x})^2} \qquad (6)$$

The tolerance $\pm s$ must be specified.

By a continuous random sample test one must determine that the standard deviation has been maintained during the manufacture.

Remarks:

For a small number of random samples, s is only a rough estimate for the standard deviation σ of the basic collection. It becomes more accurate as the number in the random sample is increased. The value x of the tested parameter is 68.3% of all of the strain gauges which make up the basic collection in the range $\bar{x} \pm \sigma$. At 95% of all strain gauges, it lies in the range $\bar{x} \pm 2\sigma$ (see DIN 1319).

1.7. Presentation and publication of measurement results

The type of presentation of test results is given in the individual sections on the characteristic variables being tested. In addition, the following data must be given.

Type notation according to section 1.3.3.

Family notation according to section 1.3.4, if the test is going to be carried out according to 1.4 b and is to be characteristic for a strain gauge family.

Lot number according to section 1.3.2.

The adhesive use, the adhesion method and possibly the covering agent according to section 1.3.1.

The measurement current applied according to section 1.5.3.

All deviations of the measurement conditions from this guideline.

The year of the test.

The publication is to follow Table 1 and be given in each shipment, in technical data sheets or as agreed.

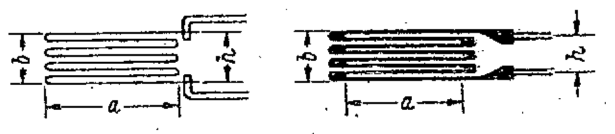

Figure 3. Measurements of the strain gauge measurement grid.

2. CHARACTERISTICS TO BE SPECIFIED

2.1. Type notation

The type notation must be a unique characterization of the strain gauge which cannot be confused, which makes it possible to obtain all the possible technical information without error.

The type of type notation is left up to the manufacturer. One can use mute keys, partially indicating keys or fully indicating keys.

2.2. Manufacturing lot

The manufacturing lot is characterized by the manufacturer in such a manner that he can collect the strain gauges from different packages without any compromise, provided they have the same lot numbers.

2.3. Strain gauge structure

Data on the structure of the strain gauges and the materials used are desirable provided that manufacturing secrets of the manufacturer are not revealed. For example:

The materials in the components, for example the strain sensitive elements, possible intermediate conductors, connectors and the carrier,

The structure of the measurement grid, for example, wire or foil version, flat grid (meandering curve in a plane) or flat coil,

The way in which the measurement grid is embedded, for example, a measurement grid recessed into the carrier, a measurement grid opened on one side, a freely carried measurement grid with auxiliary carrier,

The arrangement of the measurement grids for multiple strain gauges, whether they are on the plane or above each other.

2.4. Dimensions

2.4.1. Conduction elements

The diameter and the thickness of the strain gauge conduction elements are to be specified (measurement grid, intermediate conductor, connections).

2.4.2. Measurement grid

The active length and the width of the measurement grid, Figure 3, (measurements a and b) are to be specified as well as the dimensions h_1 to h_4 according to section 3.13.1, Figure 21, which are important for thermal stress errors. The dimension a should include the reversal loop in the case of wire measurement grids. In the case of foils, it should include the net length without the transverse bridges.

The following tolerances are to be maintained:

For dimensions ≥ 10 mm ± 5%,
< 10 mm ± 10%,
< 3 mm ± 20%.

To simplify storage logic, it is suggested to classify the measurement grid lengths according to the size standards (DIN 323). By combining the values in the blocks from the series /7

$R_a3: 0,5 - 1 - 2 - 5 - \boxed{10 - 20 - 50 - 100 - 200}$

and

R 40/12 (1,5 . . . 6), R 40/16 (6 . . . 15):
$\boxed{0,6 - 1,5 - 3 - 6} - 15 - 39 - 60 - 150 - 300$

with the series

$\boxed{0,6 - 1,5 - 3 - 6 - 10 - 20 - 50 - 100 - 200 \text{ mm}}$

it is possible to achieve a length gradation which satisfies practical requirements and which includes most of the commercial strain gauge types (see also DIN 3).

For strain gauges with nonuniform measurement grid length, it is necessary to give the average length if possible. Where this does not make sense, for example, for spiral membrane rosettes, etc., measurement sketches are to be provided.

2.4.3. Measurement grid carriers

The length and width of the measurement grid carrier, Figure 4, are to be specified (dimensions c and d). If asymmetric, the central axes (dimension c_1 and d_1) are to be measured.

Other rectangular shapes are to be measured in a suitable way. The parts of the measurement grid which go outside of the carrier have the task of supporting the strain introduction into the measurement grid. Several characteristic parameters of the strain gauge (for example, the k factor, transverse sensitivity, creep) are influenced when these parts are shortened below a critical dimension. If a manufacturer expressly allows the cutting of the strain gauge, he must give minimum values for the dimensions e and f. The data determined according to this

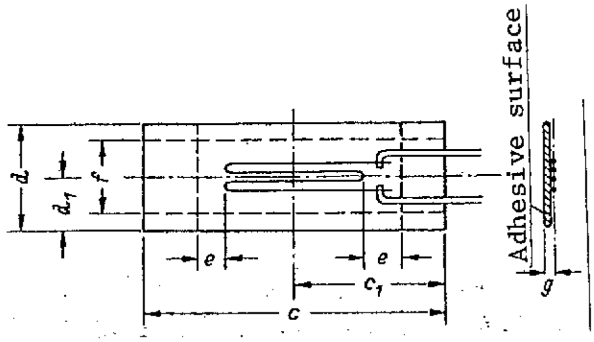

Figure 4. Measurements of the measurement grid carrier.

guideline must be valid for this minimum dimension.

Tolerances according to DIN 7168 must be "roughly" maintained for the carrier dimensions.

The distance between the central plane of the measurement grid from the adhesive surface is to be specified (dimension g).

2.5. Adhesives which can be used

The adhesive recommended by the strain gauge manufacturers should be contained in the technical data sheets. If several alternates are listed, it is necessary to specify the adhesive with which the strain gauge parameters were determined, and these must be especially marked. In this way, the manufacturer guarantees that the technical data will be applicable according to the conditions given in this guideline, if properly applied. [10].

2.6. Use of the adhesive

Detailed indications must be made regarding the adhesion procedure used to test the strain gauge.

If several adhesion methods are recommended by the manufacturer, it must be clear which of the methods was used for determining the parameters [10]. The consequences of a deviation from the standard procedure should also be mentioned.

The following data must be given, as far as the methods used are concerned. (If this data is contained in special data sheets, prospectus application instructions, etc., then this only has to be mentioned; it does not have to be repeated in the test protocol):

1. Special pretreatment:

   Storage conditions (temperature, humidity) and other measures which affect the measurement results.

2. Pretreatment of the application point:

   The procedures are to be described in detail. If equipment or materials are used which are not generally available, the names must be spelled out and the manufacturer mentioned if necessary.

3. Adhesive use:

   Adhesives and similar agents: name, mixing ratio, storage time, storage conditions, etc.

   Welding: manufacturer and type of welding device.

   Instrument settings.

   Other methods: Appropriate data must be provided.

4. Application methods:

Time, temperature, relative air humidity, heating and cooling rate, pressing pressure, details of the binding agent application. The layer thickness which is produced with the prescribed application method between the strain gauge and the component must be mentioned (average value). The material and shape of the welding electrodes, pressing pressure, current intensity and pulse duration or other corresponding data must be given. Other methods must be described in all detail.

2.7. Sample number of a package

The number of strain gauge samples in a package is to be indicated on the packages as well as in the prospectus of the data sheets.

3. PARAMETERS TO BE TESTED

3.1. Strain sensitivity (k-factor) at room temperature

3.1.1. Definition

The strain sensitivity of the strain gauge is expressed as the quotient of the relative resistance change $\Delta R/R_0$ and the strain ε

$$k = \frac{\Delta R/R_0}{\epsilon} \qquad (7)$$ /8

The strain sensitivity is found to be an unknown number and is called "k factor".

3.1.2. Measurement installation

The measurement of a k factor is performed on a bending beam which is loaded in bending along its useful length. The bending beam should be made of a fine grain steel and its proportionality limits should correspond to a strain of at least $3500 \cdot 10^{-6}$ m/m. Suitable heat treatment phases should be coordinated with the various processing phases so that eigen stresses are eliminated, if possible. The cross section of the bending beam should be square with a sidelength of at least 25 mm.

The transverse contraction number of the bending beam is to be determined with an error of $\leq 3\%$ and must be published.

The distance between the end points of the useful length and the application points of the bending moment should not be less than three times the beam thickness.

The bending beam is to be installed in a very rigid loading device so that a constant bending moment can be applied in both directions in sequence. The bending moment should be applied by a path indication and not by forces. The advantages of specifying a path are the following:

The bending radius becomes independent of the temperature changes (a temperature change of +1° C changes the elasticity modulus of steel by $\approx -0{,}3‰$ and therefore changes the strain by $\approx +0{,}3‰$) for a bending beam subjected to forces).

The bending beam can only creep slightly.

This system only has a small tendency to oscillate and is therefore easier to operate.

Over the useful length of the beam, the maximum average surface strain of $\epsilon_p = \pm 3 \cdot 10^{-3}$ m/m must be possible. It must be adjustable to $\pm 10 \cdot 10^{-6}$ m/m.

The average strain ε_p is to be determined to within ±0,2% or $\pm 2 \cdot 10^{-6}$ m/m every time the k factor is measured.

Position dependent deviations of the surface strain from the average value are possible because of adjustment errors and local variations in the modulus of elasticity. It is desirable to make the error caused by this less than ±0,5%. It can be averaged from frequent measurements and should be considered.

Remarks:

In order to determine the average surface strain ε_p of a circularly bent beam, we suggest the following method:

a) Determination of the bending magnitude p using a curvature meter, Figure 5.

b) Calculation of the surface strain ε_p of the bending beam: if p_1 is measured among the concave side we have

$$\epsilon_p = \pm \frac{h}{a^2/p_1 + p_1 + h} \tag{8a}$$

If p_2 is measured on the convex side we have

$$\epsilon_p = \pm \frac{h}{a^2/p_2 + p_2 - h} \tag{9b}$$

3.1.3. Measurement methods

d) The test is to be carried out for each strain gauge types according to section 1.3.3 and for each manufacturing sample according to section 1.3.2. Also the running random sample control according to section 1.6 is necessary. For the first determination of the k factor and its tolerance of each manufacturing lot, at least five independent random samples are necessary. One is enough for control. The density of controls is determined by the uniformity of the running production.

b) The strain gauges are attached to the bending beams, one-half on the top and one-half on the bottom according to section 2.5 and 2.6, and the storage conditions given in section 1.5.6 are maintained. The measurement direction of the strain gauges must be parallel to the longitudinal axis of the bending beam. Deviations of up to ±1° are tolerated.

c) The bending beam is installed in the loading device and the strain gauges are connected to a measurement instrument described in section 1.5.1.

d) The bending beam is loaded three times at ± or $\mp(1\,100 \pm 50)\,10^{-6}$ m/m, respectively.

e) The bending beam is unloaded and the zero reading is taken.

f) The bending beam is loaded in one direction until $|\epsilon_p|$ has reached the value $(1000 \pm 10) \cdot 10^{-6}$ m/m and the relative resistance change $\Delta R/R_0$ of the strain gauge is measured.

g) The bending beam is unloaded and measured.

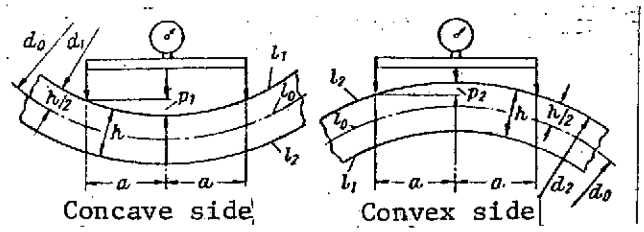

Figure 5. Curvature measurement on a bending beam.

h) The bending beam is loaded in the opposite direction until $|\epsilon_p|$ has the value $(1000 \pm 10) \cdot 10^{-6}$ m/m and the relative resistance change $\Delta R/R_0$ of the strain gauge is again measured.

i) The bending beam is unloaded and measured.

Remarks:

The strain maxima ε_p as well as the zero points of the bending beam are controlled with the curvature meter.

By ϵ_p and $\Delta R/R_0$ we mean the differences compared with the initial state of measurements according to section c). The measurements given in sections g) and i) are not used for evaluation. They are used for control of the application.

3.1.4. Evaluation

a) The evaluation of the measurement results is done according to section 1.6 d. First the measured values must be corrected according to section 3.1.3. /9

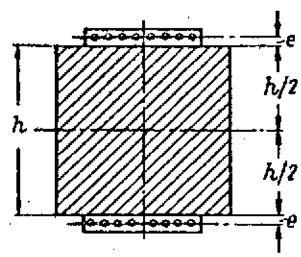

Figure 6. Distance between bending beam and measurement grid.

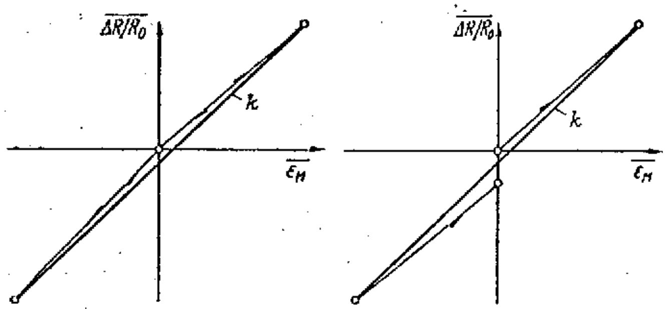

Figure 7. Examples of definition of a k factor.

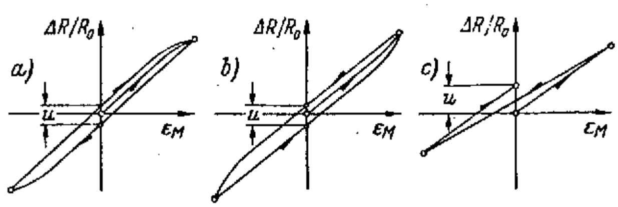

Figure 8. Types of mechanical hysteresis.

a_1) The correction of the measurement grid strain, Figure 6.

The distance between the measurement grid from the surface of the bending beam must be determined (dimension e).

The strain of the measurement grid is

$$\epsilon_M = \epsilon_p \cdot (1 = \frac{2e}{h}) \tag{9}$$

a_2) Correction of the relative resistance change.

The resistance of the connection line R_K between the strain gauge and the measurement instrument must be determined..

The measured relative resistance change

$$\zeta = \frac{\Delta R}{R_0 + R_K}$$

is to be corrected according to equation

$$\frac{\Delta R}{R_0} = \zeta (1 + \frac{R_K}{R_0}). \tag{10}$$

The magnitudes of the average values are added and are divided by the sum of magnitudes of the positive and negative strains $\overline{\epsilon}_M$. The k factor is determined according to

$$k = \frac{|\overline{\Delta R/R_{o\ pos}}| + |\overline{\Delta R/R_{0\ neg}}|}{|\overline{\epsilon}_{M\ pos}| + |\overline{\epsilon}_{M\ neg}|} \tag{11}$$

In the diagrams, Figure 7, the inclination of the connection lines between the two extreme values determines the k factor.

b) The result of measurements is only applicable for the manufacturing lot from which the sample was taken. If sequential manufacturing lots of the same strain gauge type were produced under identical conditions using identical materials and methods, the results can be used for a continuous averaging.

3.1.5. Representation and publication

The k factor is to be added as a numerical value to the tolerance of each strain gauge package. The adhesive used for testing, the adhesion method, the measurement current and the transverse contraction number of the test rod must be mentioned in prospectus and technical data sheets. In addition, they must contain a nominal value for the k factor and there must be a value for the tolerance for any strain gauge type or strain gauge family.

3.2. Mechanical hysteresis at room temperature

3.2.1. Definition

By mechanical hysteresis of a strain gauge we mean the differences in the reading between an increasing and decreasing strain load for the same strain values of the test specimen. The mechanical hysteresis can have various origins. Therefore it can have various effects.

In the case of strain gauges, one often observes the behavior given in Figure 8a. It is likely that certain hysteresis phenomena in the carrier and adhesive are responsible for this during the loading process.

The hysteresis curve shown in Figure 8b is also a possibility.

Geometric or matrix changes in the range of plastic deformations of the measurement grid material can produce resistance changes which remain, so that a figure is produced according to Figure 8c.

By the superposition of several effects, it is possible to obtain other curves.

By the mechanical hysteresis of the strain gauge in the sense of this guideline, we mean the largest difference at the origin in the abscissa between the increasing and the decreasing leg of a curve which extends over the complete cycle with the extreme values of ± and $\mp 1000 \cdot 10^{-6}$ m/m , respectively, (path u in Figure 8).

3.2.2. Measurement installation

The measurement installation given in section 3.1.2. is to be used for determining the mechanical hysteresis.

3.2.3. Measurement procedure

a) The test is carried out as a type test according to section 1.6a for each strain gauge family and with a type according to section 1.4b. In any manufacturing lot, a random sample is taken according to section 1.6c. / 10

b) See section 3.1.3b.

c) The bending beam is to be installed in the load device. Make sure that the strain gauge is not preloaded.

d) The strain gauge is connected to a measurement instrument according to section 1.5.1 and the zero point is compensated for and recorded.

e) During the first and third load cycle, the measurement values are recorded at the step

$$\epsilon_p = 0 / +(1000 + 50) / 0 / -(1000 - 50) / 0$$

and

$$\epsilon_p = 0 / -(1000 - 50) / 0 / +(1000 + 50) / 0$$

(Strain of the bending beam in 10^{-6} m/m).

At the beginning of the third cycle the zero point is again equalized and recorded.

The cycles are to be carried out approximately in ten minutes.

f) The strain of the bending beam is to be checked at each stopping point. The reading is to be referred to the observed actual value of strain, not to the nominal values.

g) If previously agreed, the hysteresis can also be measured for other strains. The values $\pm 500 \cdot 10^{-6}$ m/m, $\pm 2000 \cdot 10^{-6}$ m/m and $\pm 3000 \cdot 10^{-6}$ m/m are preferred.

h) The measurement can be combined with the k factor measurement according to section 3.1.3.

3.2.4. Evaluation

a) The strain gauge reading is recalculated into strain values using the k factor given in section 3.1.

b) The greatest difference in the measured values at the zero point of the abscissa (path u in Figure 8) is considered the hysteresis of the individually tested strain gauges.

c) The arithmetic mean and the standard deviation are determined from the hysteresis values for each cycle separately (see section 1.6e).

3.2.5. Presentation and publication

a) The hysteresis is indicated as a numerical value together with the strain values $[(m \pm n) \cdot 10^{-6}\ m/m]$ for the first and third load cycle.

b) When the hysteresis is determined for various strains after agreement has been reached, the average values and the confidence limits are determined corresponding to section 3.2.4 for each of the largest strains, as a function of strain. The abscissa scale is $20 \cdot 10^{-6}$ m/m per mm and the ordinate scale is $1 \cdot 10^{-6}$ m/m.

c) The data is published in the form of technical data sheets or in a similar manner. The sheet must contain the following in addition to the numerical value specified in subsection a and possibly the diagram mentioned in subsection b:

The type notation of the strain gauge according to section 2.1,

The adhesive used according to section 2.5,
The adhesive method used according to section 2.6,
The measurement current and
The date of testing

3.3. Linearity error at room temperature

3.3.1. Definition

By linearity error we mean the deviation of the measured value $\Delta R/R_0$ from the corresponding values $k\epsilon_M$ determined by the k factor.

The linearity error is, in particular to be attributed to mechanical hysteresis phenomena in the strain gauge components, so that in general part of the hysteresis error is also expressed as a linearity error. In particular, a quadratic term in the resistance characteristic has an effect at large strains, which can be attributed to matrix changes within the measurement grid [11].

In the following we distinguish between the two strain ranges:

strain range up to $\pm 3 \cdot 10^{-3}$ m/m,

strain range above $\pm 3 \cdot 10^{-3}$ m/m.

3.3.2. Measurement installation

a) The measurement installation given by section 3.1.2. is to be used for the strain range up to $\pm 3 \cdot 10^{-3}$ m/m .

b) For the strain range up to the largest strains above $\pm 3 \cdot 10^{-3}$ m/m, the measurement installation according to section 3.4.2. is recommended with which strains up to $\pm 15 \cdot 10^{-2}$ m/m can be produced.

c) The electrical values are to be determined for the strain range up to $\pm 3 \cdot 10^{-3}$ m/m using an instrument given in section 1.5.1. For the strain range above $\pm 3 \cdot 10^{-3}$ m/m an extended measurement uncertainty of $\pm 50 \cdot 10^{-6}\ \Omega/\Omega$ or $\pm 2\%$ is allowed. Linearity errors which are caused by the circuit used must be corrected.

3.3.3. Measurement methods

a) For the strain range up to $\pm 3 \cdot 10^{-3}$ m/m the test is carried out for each strain gauge type according to section 1.6a_3, in contrast to section 1.4b.

b) See section 3.1.3 b.

c) Place the bending beam into the load device, connect the strain gauges to the resistance measurement device and record or equalize the zero point.

d) The bending beam is only to be deformed in one direction, so that the random samples distributed on both sides of the beam are each one-half extended and compressed respectively.

d_1) In the strain range up to $\pm 3 \cdot 10^{-3}$ m/m, the bending beam is to be deformed in steps of $500 \cdot 10^{-6}$ m/m up to a maximum value (first load).

d_2) In the strain range above $\pm 3 \cdot 10^{-3}$ m/m, the bending beam is to be deformed starting at the zero point in at least ten equally large steps up to the maximum value specified by the manufacturer (first load). In the case of an irregular but reproducible resistance strain characteristic, as many additional measurement points are to be introduced which will make the variation clear. /11

e) During each deformation stage, the actual value of the bending strain is to be determined and the measured values of the strain gauge are to be recorded. The stay time should not exceed two minutes per stage.

If different linearity errors result for the positive and negative deformation range, a random sample of at least five pieces must be used for each direction in order to obtain a useful statistical result.

f) The bending beam, in the case of a strain range up to $\pm 3 \cdot 10^{-3}$ m/m, is to be brought back to its initial position and after this is deformed a second time in the same direction up to the maximum value, and then it is again returned to the initial position. No measurements except a check of the maximum beam strain are required for control (second load).

g) Sections d_1 and e are to be repeated (third load).

3.3.4. Evaluation

a) The measured values are to be corrected according to sections 3.1.4 a_1, a_2.

b_1 For each strain range up to $\pm 3 \cdot 10^{-3}$ m/m, the relative deviations in the strain reading $\Delta R/R_0$ from its nominal value $k\epsilon_M$ are to be determined for each load step:

$$f_1^* = \left(\frac{\Delta R/R_0}{k\epsilon_M} - 1\right) 100\% \quad . \tag{12}$$

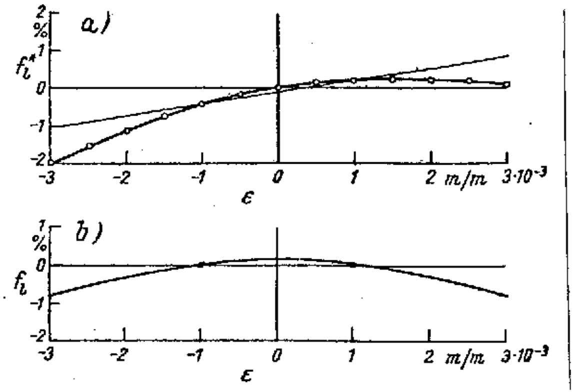

Figure 9. Diagram examples for representing the linearity error.

a- for elimination of the sample scatter of the k factor from the linearity error for strains up to $\pm 3 \cdot 10^{-3}$ mm

b- corrected linearity error for strains up to $\pm 3 \cdot 10^{-3}$ m/m

From the results, one forms the average values and these are plotted as a function of strain, for the first and third load, Figure 9a.

The secant is passed through the curve points at $\pm 1 \cdot 10^{-3}$ m/m and the deviation in the curve from this secant is established as the linearity error f_l. In this way it is possible to eliminate the example scatter which is still contained in f_l^*. The standard deviation is not determined because the example scatter affects it noticeably, Figure 9b.

Remarks:

The somewhat unusual method for determining the linearity error for the strain range up to $\pm 3 \cdot 10^{-3}$ m/m is the result of the fact that, on the one hand, neither the hysteresis at $\pm 3 \cdot 10^{-3}$ m/m nor the example scatter of the k-factor are to affect the linearity error, and on the other hand, one wishes to observe the possible bend in the resistance strain characteristic near the origin in the curve representing the linearity error.

b_2) In the case of the strain range above $\pm 3 \cdot 10^{-3}$ m/m, the linearity error is determined using the $\Delta R/R_0 - \epsilon_M$ characteristic. The evaluation can be found from section 3.4.4.

3.3.5. Presentation and publication

In the case of the strain range up to $\pm 3 \cdot 10^{-3}$ m/m, the linearity error f_1 is plotted as a diagram for the first and third load cycle (see Figure 9b).

The ordinate scale is 10 mm per percent and the abscissa scale is 20 mm per $1 \cdot 10^{-3}$ m/m.

In the case of the strain range above $\pm 3 \cdot 10^{-3}$ m/m, the average strain gauge characteristic is to be presented according to section 3.4.4c, Figure 11, with the standard deviations. The scale is selected so that the maximum strain corresponds to about 15 cm.

The publication is in the form of technical data sheets or similar format.

3.4. Maximum strain capacity at room temperature

3.4.1. Definition

By the maximum strain capacity of a strain gauge, we mean the strain at which its characteristic (resistance change - strain characteristic) deviates from the average characteristic of the type by more than ±5%. Deviations can be caused by various effects with large scatter such as:

The fracture of a measurement grid or one of the conductor parts, which makes up the strain gauge,

The connection between the strain gauge and the sample load between the measurement grid and the carrier are severed.

A change in the k factor with strain because of matrix changes of the measurement grid at large strains does not limit the usability of the strain gauge as long as this effect is reproducible and if the related nonlinearity is accepted.

Linearity errors which result from the measurement circuit must be excluded. They do not belong to the errors of the strain gauge.

3.4.2. Measurement installation

a) For producing the strain, about up to $15 \cdot 10^{-2}$ m/m, one uses the bending beam shown in Figure 10 which is narrower over a short range in the center. It is made of St 37 steel as has been developed in the BAM and is used in the device mentioned in [11]. A constant bending moment is produced in the beam by loads at the four indicated points, in the central region of the beam. Not the forces but the deformation paths are specified in order /12
to eliminate the effects of nonlinearity and time dependence of the stress-strain diagram of steel on the strain of the beam.

In order to avoid unacceptably large and poorly reproducible compression stresses in the longitudinal direction of the beam, it is necessary for these supports to be sufficiently mobile, and the beam must be able to move sufficiently easily. The beam can be used many times.

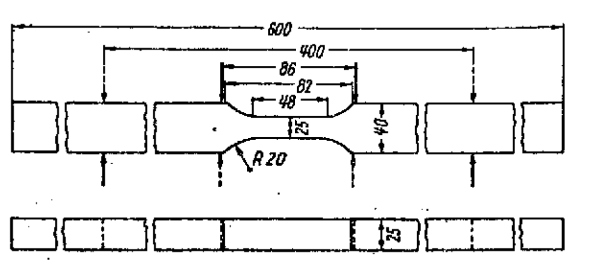

Figure 10. Bending beam for determining maximum strain capacity of strain gauge.

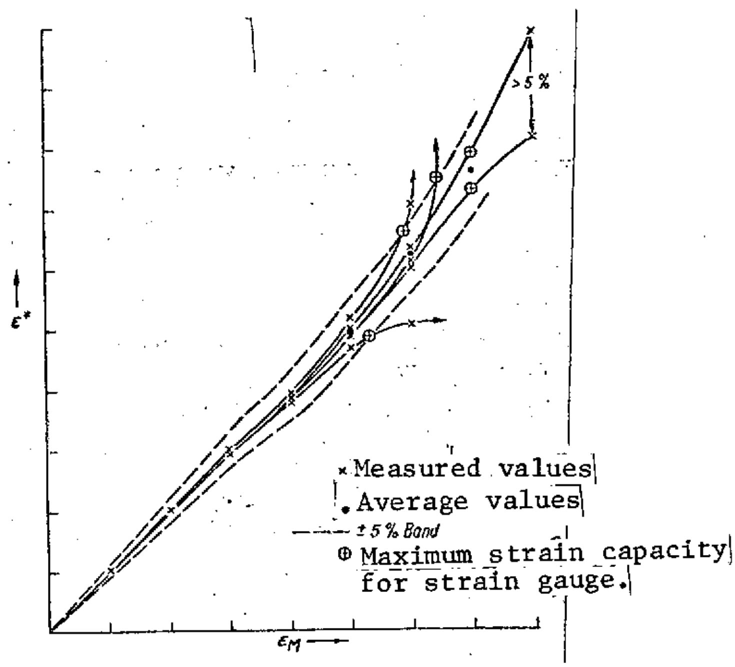

Figure 11. Diagram example for determining maximum strain of strain gauges.

b) The strain of the bending beam is to be measured using a sufficiently accurate comparison strain measurement instrument, such as a knife edge strain gauge with a strain gauge and a strain reducer by a factor of about 1:80. The error in this comparison strain measurement device including all additional components cannot exceed $\pm 50 \cdot 10^{-6}$ m/m or $\pm 2\%$ of the nominal value.

c) The electrical measurement installation for measuring the relative resistance change of the strain gauge can reach an error level of $\pm 50 \mu\Omega/\Omega$ or $\pm 2\%$ of the corresponding value, in contrast to the specifications in section 1.5.1.

3.4.3. Measurement methods

a) The tests are to be carried out for each strain gauge family and one type, according to Section 1.4b. A random sample is to be taken from a manufacturing lot according to Section 1.6 for carrying out tests for positive and negative strain.

b) After storage of the strain gauges according to Section 1.5.5, they are attached to the bending beam according to Sections 2.5 and 2.6.

c) The comparison strain measurement device is to be attached on the beam in such a way that the measurement path ends are at least 2 to 3 mm from the ends of the parallel part of the useful beam length.

d) The bending beam is to be loaded in stages of $\leq 10\%$ of the maximum strain of the strain gauge to be expected. Once a load stage has been reached, the readings of the strain gauge and the comparison strain measurement devices are recorded.

3.4.4. Evaluation

a) The systematic errors of the comparison strain measurement device are to be appropriately corrected, especially for the error caused by the beam curvature. In addition, the sample strain is to be recalculated into the measurement grid strain according to Section 3.1.4a.

b) The strain reading ϵ^* of the strain gauge is calculated from the relative resistance change and from the k factor determined in Section 3.1:

$$\epsilon^* = \frac{\Delta R/R_0}{k} \tag{13}$$

c) First, the mean characteristic is determined according to the following procedure:

From the readings ϵ^* of a stage, one forms the average value $\bar{\epsilon}^*$. This is then to be used for the average characteristic line, if all of the individual values lie within a tolerance band of ±5%. If the 5% limit is exceeded, then the strain gauge having the greatest magnitude difference is to be excluded for the present and the subsequent strain levels. For the remaining strain gauges, one again calculates the average value $\bar{\epsilon}^*$ and again checks whether the readings satisfy the tolerance condition, with respect to the new average value. In case there is an excess again, one proceeds as before until the condition is satisfied and a valid average value $\bar{\epsilon}^*$ has been found.

These points are plotted in a diagram as shown in Figure 11 and a curve is drawn. (This curve represents the characteristics for the strain range $> \pm 3 \cdot 10^{-3}$ m/m as required in Section 3.3.5.)

d) The ±5% tolerance band is indicated on the average characteristic line according to Section c; also, the individual readings of the strain gauges which are also to be connected by characteristic lines, separately for each strain gauge. The point at which an individual strain gauge characteristic line intersects the tolerance limits for the first time is the maximum strain capacity of the strain gauge. /13

e) If all of the maximum strains lie within the working range of the measurement installation, then the average value is formed and the standard deviation is found according to Section 1.6d. Otherwise, the individual values and the strain limits of the measurement installation are to be indicated.

3.4.5. Representation and Publication

If all of the values of maximum strains lie in the working range of the measurement installation according to Section 3.4.4, then its average value and the standard deviation are to be given in numerical form. Otherwise, the individual results are to be given in the form of a nomogram. Those strain gauges whose strain capacity exceeds the working range of the measurement installation are to be characterized by points with arrows at the end of the working range, Figure 12.

3.5. Resistance at Room Temperature

3.5.1. Definition

By the resistance of the strain gauge, we mean the electrical resistance measured according to Section 1.5.4 between the two wires for connecting the measurement cable, metal bands, connection flanges or similar parts at room temperature.

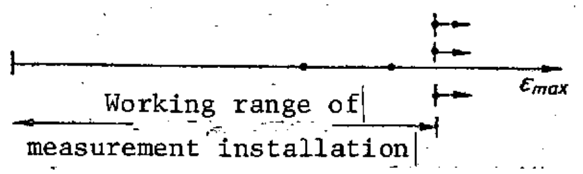

Figure 12. Type of representation when maximum strain is greater than working range of measurement installation.

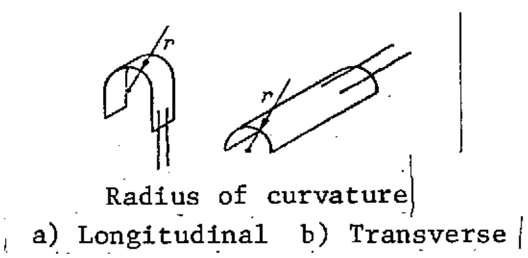

Figure 13. Curvature directions on a strain gauge.

At the present time, the nominal values 120 Ω and 600 Ω are primarily found, and to a lesser extent, 300, 350, 500, and 1000 Ω. The value 350 Ω is becoming more popular for measurement transducers operating with strain gauges. Therefore, it is suggested that the values 120, 350, and 600 Ω be preferred.

The deviation in the individual resistance from the nominal value allowed by the producer is called "resistance spread." If the resistance spread of a manufacturing lot is too large for practical application of the strain gauge because of the manufacturing process, it is possible to divide the lot into tolerance groups by sorting it. The average value of the tolerance limits is called "package nominal value" and one half of its difference with respect to the nominal value is called the "package tolerance."

3.5.2. Measurement Installation

The measurement installation used for the determination of the resistance has an allowable error of ±0.1% under comparable conditions. The error under repetitive conditions (see DIN 1319, sheet 3) cannot exceed 0.02%.

The measurement current is not allowed to change the resistance of the measured strain gauge by more than 0.1%.

3.5.3. Measurement Method

The resistance check of the strain gauge is to be carried out as a sample test, according to Section 1.6b.

If the strain gauge manufacturer is successful in maintaining the nominal resistance value within the range of the packing tolerance, then a continuous sample test, according to Section 1.6d, is sufficient.

The electrical resistance is measured in the usual way. The strain gauge must lie on a flat base during the measurement.

Fluctuations in air humidity can make the plastic carrier of the strain gauges expand or shrink and, therefore, can produce resistance changes. Therefore, it is important to maintain the storage conditions described in Section 1.5.6.

3.5.4. Evaluation

The measurement results are evaluated for random sample tests according to Section 1.6 using the indications given there. In the case of sample tests, no special evaluation is required.

3.5.5. Representation and Publication

In prospectus and technical data sheets, it is necessary to mention the nominal resistance, resistance spread, and package tolerance.

Each strain gauge package must contain indications on the package nominal resistance and the package tolerance.

3.6. Maximum Electrical Load at Room Temperature

3.6.1. Definition

The electrical maximum load of a strain gauge depends primarily on the heat conduction through the component to which the strain gauge is applied. Therefore, the properties and dimensions of the sample body being used for tests are to be specified, as well as the adhesion conditions for the strain gauge.

At the present time, a suitable testing method is not known. The treatment of this problem is, therefore, deferred in this guideline.

3.7. Smallest Radius of Curvature at Room Temperature

3.7.1. Definition

The flexibility of a strain gauge is characterized by the smallest radius of curvature which it can withstand in one direction without additional measures (for example, warm shaping) without experiencing defects detectable from the outside. The larger of the two minimum values determined at room tempera- /14 ture according to Section 1.5.4 for the longitudinal and transverse directions is the smallest radius of curvature r_{min} of the strain gauge, Figure 13.

Remark: The test does not give any information regarding possible changes in the strain gauge properties.

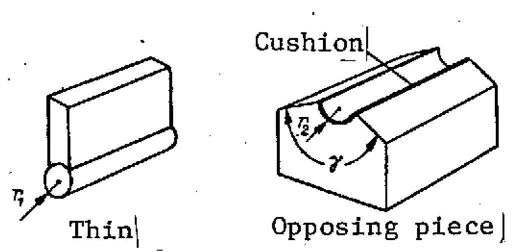

Figure 14. Device for determining the smallest radius of curvature.

3.7.2. Measurement Installation

A set of fins and padded opposite pieces are required as shown in Figure 14, having the radii r_1 and r_2 with millimeter gradation. The padding should have a thickness between 1 and 2 mm and should not be too soft so that the strain gauge is completely pressed on the fin. The radii r_2 of the opposing pieces can only be larger by one strain gauge thickness at the most than the radii r_1 of the fins. The covering angle y of the opposing pieces should be at least 120°.

3.7.3. Measurement Method

The test is to be carried out for each strain gauge family using a type having a 6 mm active measurement grid length at room temperature, according to Section 1.5.4. The result applies for all types of the strain gauge family.

For the tests, a strain gauge with the fin is pressed onto the opposing piece. A strain gauge which is longer than the surfaces which are in contact with it is tested along its length in stages. The transverse direction is tested in the same way. The strain gauge cannot experience any jumps in the measurement grid carrier, no interruptions in the conductor parts or connection points. Also, no other damage which would influence the usability is permissible. The tests with the smallest possible radius must be successful in the first experiment using at least three sequential strain gauges of a random strain gauge sample, which are taken from a manufacturing lot as described in Section 1.6. A previous experiment with a larger radius excludes the strain gauge from any further evaluation or test.

3.7.4. Evaluation

The test result does not have to be evaluated. If the two radii of curvature in the longitudinal and tranverse directions are different, the greater of them is accepted.

3.7.5. Presentation and Publication

The smallest radius of curvature r_{min} is to be indicated as a numerical value in millimeters in data sheets and similar documents. No tolerance indication is required.

3.8. Strain-Related Restoring Force of the Strain Gauge at Room Temperature

3.8.1. Definition

The restoring force c_{DMS} of the strain gauge is the ratio between the applied force F and the strain ϵ which is reached for the free strain gauge which has not been attached:

$$c_{DMS} = \frac{F}{\epsilon} \tag{14}$$

It is especially important when analyzing the effect of the strain gauge on the component being tested.

The spring constant can be indicated only for a limited strain range and for a certain loading time, because after exceeding the elasticity limit of the measurement grid material, the numerical value becomes strain dependent and time dependent because of the relaxation of the plastic. Therefore, a time limit is indicated for loading the strain gauge or a certain strain rate is specified in order to obtain comparable results.

3.8.2. Measurement Installation

The following is required:

a) A measurement installation for determining the relative resistance change for the strain reading of the strain gauge.

b) A force measurement device,

c) A clamping device.

a): In order to determine the strain reading of the strain gauge, one can use a measurement instrument which is calibrated directly in "strain units" (for example, 10^{-6} m/m), considering the k factor discussed in Section 3.1. Also, the device for measuring relative resistance change can be used, as discussed in Section 1.5.1, from which the strain is calculated according to the equation:

$$\epsilon = (\Delta R/R_0)(1/k)$$

b): The force is most easily measured with weights, which are to be placed on a very light weighing container, or it is determined with a spring balance or an electrical force measuring device.

The measurement installation must have a prestress corresponding to a strain of $(100 \pm 50)10^{-6}$ m/m over 30 seconds, which is added and superimposed on the test force corresponding to a strain of $(1000 \pm 50)10^{-6}$ m/m. The prestress is required especially where not the entire force-strain characteristic is recorded.

c): A laboratory stand can serve as a clamping device.

d) The allowable measurement error for strain is $\pm 20 \cdot 10^{-6}$ m/m; for the force it is ±0.05N(±5 p) or ±2% of the applied force.

3.8.3. Measurement Procedure /15

The test is to be carried out at room temperature according to Section 1.5.4 for each strain gauge family with a type having a measurement grid length of 6 mm. At least five strain gauges must be tested from a manufacturing lot.

The strain gauges are to be attached to the two longitudinal ends between the extension strips made of a thin material, Figure 15. The extensions are designed such that sudden cross section changes are avoided. The sample is attached to them and the tensile force is introduced. The required holes must be located in the central axis of the strain gauge. The allowable angular error between the measurement grid device and the force application direction is ±2°. The strain gauge is connected to the strain or resistance measurement unit in the usual way. Since the strain gauge cannot give off the heat produced by the current flowing through it to the component, the measurement voltage (bridge supply voltage) must be reduced to 10% of the maximum value specified by the manufacturer. If this is done with resistances, then their influence on the reading must be considered.

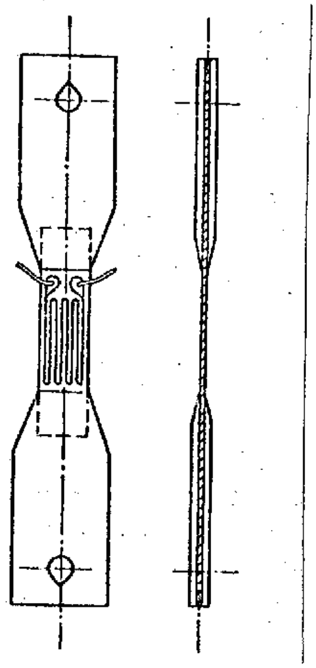

Figure 15. Clamping of strain gauges for measuring spring constants.

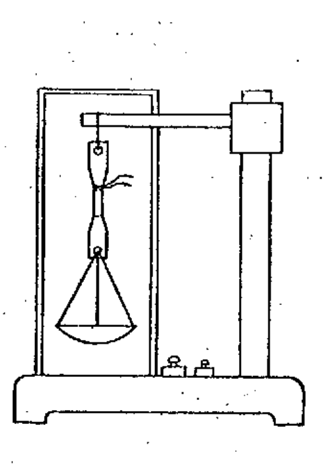

Figure 16. Device for measuring spring constants, schematic.

The installation is protected against moving air by means of a cover which allows the weighing pan to move freely, Figure 16. The sample is first preloaded according to Section 3.8.2b. Then the test force is applied.

The measurement applies for all strain gauge types for which the measurement grid has the same material and cross section. Differences in the shape and arrangement of the connections are not considered.

For strain gauges in which the measurement grid shape does not allow a measurement as described above (for example, spirals), the spring constant is calculated. For this, it is necessary to know as accurately as possible the elasticity moduli of the materials and dimensions of the individual components. The dimensions are to be examined for at least five strain gauges. The average value from the five measurements is used in the calculations.

3.8.4. Evaluation

The average value and confidence range is calculated from the individual measurements of a random sample, according to Section 1.6d.

3.8.5. Presentation and Publication

The restoring force c_{MDS} is to be indicated in N/(10^{-3} m/m) including the magnitude of the standard deviation in the data sheets.

Special data: type of time variation of the load.

3.9. Transverse Sensitivity at Room Temperature

3.9.1. Definition

A strain gauge which reacts to strains in a different manner than by resistance changes in the longitudinal direction is called "sensitive to the transverse direction." The transverse sensitivity q is defined as the ratio of the strain sensitivities in the uniaxial strain state perpendicular and along the measurement direction of the strain gauge, k_q and k_l:

$$q = \frac{k_q}{k_l} = \frac{\Delta R/R_0}{\epsilon_q} \bigg/ \frac{\Delta R/R_0}{\epsilon_l} \qquad (15)$$

In order to determine k_q and k_l, it is necessary to carry out measurements in a uniaxial strain field.

The proportionality factor k measured according to Section 3.1, therefore, is different from the factor k_l measured in the uniaxial strain field because of transverse contraction or dilatation of the bending beam.

One can also assume that the transverse sensitivity, as a rule, is less than 2% and hardly exceeds 5% in unfavorable cases. (For example, for very short and wide measurement grids.) If the transverse strain coefficient of the bending beam is $\mu = 0.28$ and if the transverse sensitivity of the strain gauge is 5%, we have $k_1 = k/(1 - q\mu) = k/(1 - 0.05 \cdot 0.28) = k/0.986$. This error which enters the measurement value scatter can be ignored and Equation (15) can be written in the following form:

$$q = \frac{k_q}{k} = \frac{\Delta R/R_0}{\epsilon_q k} \tag{16}$$

Since k must be determined in all cases, the measurement of k_1 does not have to be carried out.

Remarks: The transverse sensitivity only has to be known for measurements during the experimental stress analysis in biaxial stress fields. According to [12], values $q \leq 2\%$ are not important. Corrections are required only for the measurement results when q is greater.

3.9.2. Measurement Installation /16

a) A mechanical instrument must be capable of producing a uniaxial strain $\epsilon_1 = (1000 \pm 50) \cdot 10^{-6}$ m/m. The strain ϵ_2 normal to this cannot exceed $5 \cdot 10^{-6}$ m/m. Various devices are described. It is suggested that the devices discussed in NAS-942 [1] and ASTM E 251-64 T [3] be used, Figure 17. The granularity of the material of the bending beam must be sufficiently fine.

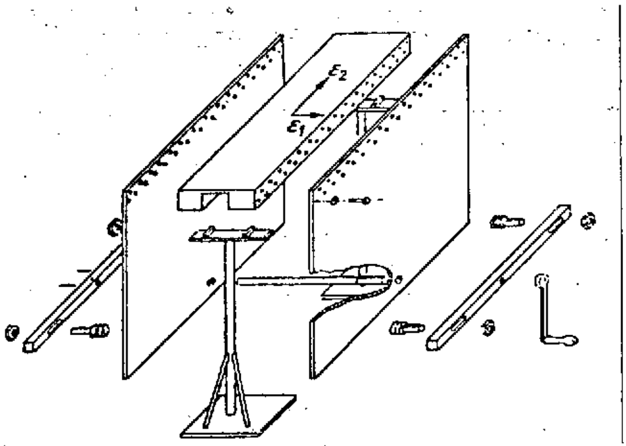

Figure 17. Device for measuring transverse sensitivity of strain gauges (according to [1] and [3]).

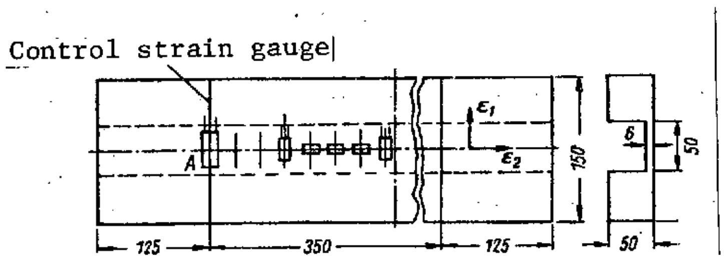

Figure 18. Bending beam for the device given in Figure 17.

The strain ε_2 of the bending beam which can occur at the individual measurement points (attachment points of the strain gauge, Figure 18), must be determined with an error tolerance of $\leq 3 \cdot 10^{-6}$ m/m. [Assuming a transverse sensitivity of the strain gauge of 1%, a reading of $(\Delta R/R_0) \cdot (1/k) = 10 \cdot 10^{-6}$ m/m is produced for a strain of the strain gauge of $\epsilon_g = 1000 \cdot 10^{-6}$ m/m. A strain ε_2 of the bending beam, which has an effect in the longitudinal direction of the strain gauge of only $3 \cdot 10^{-6}$ m/m, results in an error of 30%! Therefore, this check is very important.]

b) In order to determine the strain ϵ_1 of the bending beam, a measurement instrument is required with which $1000 \cdot 10^{-6}$ m/m can be determined with an error of <±1%. The following units or measurement methods are mentioned as examples:

— a curvature meter as suggested in the remarks in Section 3.1.2.

— one or several permanently installed strain gauges which have been calibrated as accurately as possible.

— path measurement devices for determining the distances between the two lever plates between the loading points. The correspondence between path and strain must be found by calibration.

c) In order to determine the strain ϵ_2 of the bending beam, a strain gauge is required with an error of less than $1 \cdot 10^{-6}$ m/m. Strain gauges with point strain pickups are suggested. Their measurement base should not be higher than 25 mm. They are to be applied centrally over the measurement point of the individual strain gauges. The values of ϵ_2 found for the individual measurement points are to be noted.

d) A device according to Section 1.5.1 is used for determining relative resistance change.

Remark: It has been found that, by using a heat treated, fine grained steel instead of the aluminum alloy mentioned in [1], it is possible to have a homogeneous strain field in the useful region of the bending beam (Figure 18).

3.9.3. Measurement Procedure

a) The test is required for each strain gauge type. For this, a random sample is taken from a finished lot according to Section 1.6a$_3$.

b) The strain gauges are attached to the bending beam according to Sections 2.5 and 2.6, after storage according to Section 1.5.6. An indication must be made that the same adhesion conditions and agents are used for determining the q factor as for determining the k factor. The measurement installation of the strain gauge must coincide with the central axis of the bending beam. Deviations of up to 1° are tolerated (see also Figure 18).

c) See Section 3.1.3c.

d) The bending beam is loaded three times with a maximum strain $\epsilon_1 = (1000 \pm 50) \cdot 10^{-6}$ m/m and then it is unloaded.

e) The zero point of the strain gauge is measured and noted.

f) See Section 3.1.3f.

The maximum strains, as well as the zero points of the bending beams, are to be checked using the measurement instruments described in Section 3.9.2a to c. The strain at the surface of the bending beam below the strain gauge is important.

3.9.4. Evaluation

a) From the measured values $(\Delta R/R_0)_1$ to $(\Delta R/R_0)_n$, one determines the arithmetic mean $\bar{x}$ and the standard deviation according to Section 1.6d.

b) When the resistance of the connection line in series with the strain gauge is more than 1% of the strain gauge resistance, the average measured value is to be corrected according to Equation (10) (see Section 3.1.4a).

c) The transverse sensitivity q is to be determined according to Equation (16) and an additional correction of the bending beam strain ϵ_2 according to Equation (17):

$$q = \frac{R/R_0 - \epsilon_2\, k}{\epsilon_1\, k}\, 100\% \qquad (17)$$

The results apply for all strain gauges of the tested type as long as no construction or manufacturing changes have been made.

3.9.5. Presentation and Publication /17

The q factor is indicated as a numerical value together with the standard deviation.

3.10. Temperature Variation

3.10.1. Definition

The temperature coefficient (TK) of a measurement point is a complex quantity which involves the temperature coefficients of the electrical resistance of the free measurement grid α_R, the strain sensitivity of the measurement grid material k_M,* and the difference between the linear heat expansion coefficient of the component material connected with the strain gauge α_B and that of the measurement grid material α_M .

$$\alpha = \frac{\alpha_R}{k_M} + \alpha_B - \alpha_M \text{ in } \frac{m/m}{K} \tag{18}$$

The coefficients α_B, α_M, and α_R are temperature dependent. Therefore, a number only represents an average value for a limited temperature range. By calculating α using conventional tables, we only obtain an approximate result. It is therefore necessary to determine the temperature variation in experiments [20].

By specially selecting and treating the measurement grid material, it is possible to manufacture strain gauges for which, at a given α_B, we have

$$\alpha_R \approx k_M (\alpha_M - \alpha_B)$$

so that, according to Equation (18), the temperature coefficient of the measurement point is approximately zero. These are called "strain gauges with a temperature coefficient which is adjusted to the linear heat exchange coefficient of the component material" or "strain gauges with adjusted temperature coefficient" for short. They are also called "self-compensating strain gauges."

Remark: A reading produced by a temperature change is an <u>error of a strain measurement and</u> must be eliminated. Three

*k_M is the strain sensitivity of the strain gauge in a homogeneous biaxial strain field $(\epsilon_1 = \epsilon_2)$. For example, it is approximately equal to the strain sensitivity of an elongated measurement grid wire and is only slightly different from the k factor of the strain gauge.

methods are used:

a) Temperature compensation using circuits.

For example, one can use wheatstone bridge circuits with so-called "half bridge" or "full bridge" circuits with all strain gauges made of the same material at the same temperature. For this, it is sufficient for the temperature variations of the connected strain gauges to agree, which must be assumed for strain gauges from the same production lot. The agreement of the coefficients α and α_B is not required. However, they should not be too different for practical reasons.

b) Use of strain gauges with adapted temperature compensation.

These strain gauges do not require a compensation circuit. They are self-compensating within the framework of the restrictions made at the introduction.

In order to give an idea of the remaining error, it is necessary to plot the residual temperature variation and the relationship between the length change and temperature for the material of the sample plate in the diagram, in addition to specifying the numerical value of the temperature compensation. In this way, the user has a possibility of correcting his measurement results.

c) Calculated corrections of a measurement result.

For this, the user requires the temperature variation diagrams and heat expansion diagrams of the sample plate material. The temperature variation at the measurement point during the measurement and the heat expansion of the sample material must be determined by the user.

3.10.2. Measurement Installation

In addition to instruments for determining the relative resistance change according to Section 1.5.1 and the temperature change according to Section 1.5.2, it is necessary to have the equipment for tempering the sample plates holding the strain gauges. In contrast to the requirements of Section 1.5.2, the temperature measurement installation can have an error equal to the greatest error of ±2° K or ±2% of the difference between the room temperature and measurement temperature, whatever is larger. Controllable ovens, thermostats, or cryostats (with dry ice or liquid gases) are used as tempering installations.

It is permissible to use measurement point switches for sequential interrogation of all strain gauges with one measurement instrument if the error caused by switching influences is no greater than $|\pm 3 \cdot 10^{-6}\ m/m|$. The temperature range for which this indication is made is left up to the strain gauge manufacturer.

The temperature changes during the measurement can be in stages or continuous, depending on the installation. One must be sure that the sample plate is uniformly tempered at the time of measurement. If continuous measurements are made, the strain gauge reading and the sample plate temperature must be recorded practically at the same time.

TABLE II. NOMINAL VALUES, CHARACTERISTIC COLORS AND SAMPLE PLATE MATERIAL FOR STRAIN GAUGES WITH A TEMPERATURE COMPENSATION ADAPTED TO THE SAMPLE MATERIAL

1	2	3
Heat exchange coefficient α_B $10^{-6}\ \frac{m/m}{K}$ (0 to 100° C)	Characteristic color for strain gauge with adapted temperature coefficient*	Sample plate (component) material (examples)
0.05 ± 0.15 (20 to 300° C)	White	"Zerodur" glass ceramic**
8 to 9	Green	Titanium
11 to 12	Red*	Steel
15 to 17	Orange*	Austenitic steels, copper
22 to 24	Black*	Aluminum
27	Yellow*	Magnesium
70	Dark blue*	Certain plastics
Undetermined	Purple*	Others

* An asterisk (*) characterizes agreement with conventional American code colors.

** "Zerodur" is a registered trademark [14, 15].

Sample plates made of various materials are required for accepting the strain gauges. The plates must have no eigen stresses so that they can be used at higher temperatures. Their thickness and dimensions are to be selected so that the plates cannot deform during the measurement. The size should be no less than $40 \times 60 \times 3$ mm³/ /18

The plates should be made of materials used in the manufacturing of the strain gauges. This is especially true for strain gauges with adjusted temperature compensation. Table II shows a summary of conventional materials. This does not imply a restriction considering the expected new materials. It is up to the strain gauge producer to determine which strain gauges are to be offerred with adjusted temperature compensation.

In order to determine the linear heat expansion coefficient α_B of the sample plate material, a dialatometer is required. It is measured using a sample taken from a plate.

3.10.3. Measurement Methods

a) The determination of the temperature variation for each strain gauge type and manufacturing lot of the measurement grid material in a type test is done according to Section 1.6. If it has been shown that the type dependence does not exist within a strain gauge family, the measurement can be restricted to a strain gauge type with a preferrable measurement length of 6 mm. The result then applies for all of the strain gauges in this family from the same lot of the measurement grid material.

b) The strain gauges are to be attached according to Sections 2.5 and 2.6, to sample plates, so that the measurement installation of the strain gauge coincides with the direction in which the heat expansion coefficient of the sample plate material is being measured. The sample plate material is to be selected according to the strain gauge application.

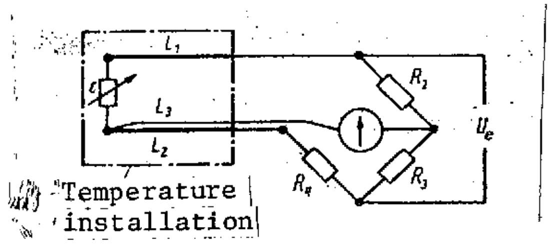

Figure 19.. Three conductor circuit for avoiding measurement errors caused by temperature effects on the connection cables.

In order to exclude any drift because of the deposition of humidity (see Section 3.2), special storage conditions are required for this measurement:

Up to application, the strain gauges are stored according to Section 1.5.6 for 72 hours in the normal climate 23/50. They are to be applied with this climate or according to Section 1.5.5, respectively.

c) A thermoelement making absolute heat contact with the sample plate is used for determining the temperature.

d) The switching of the strain gauge is done so that cable influences are eliminated. The so-called "three conductor circuit," (Figure 19), is suitable for this. The lines L_1 and L_2 are identical with respect to resistance, temperature coefficient, and thermal load. No special requirements are placed on the line L_3 if the input resistance of the reading device is sufficiently large. The connection with the strain gauges are to be made as close as possible to the measurement grid.

e) In contrast to the general storage conditions, the samples are stored in an exsiccator, for example, in phosphorous pentoxide, up to immediately before the measurement, for at least 72 hours.

f) During the measurement, the strain gauges must be protected against possible direct head radiation, for example, they are covered with aluminum foil.

g) The temperature of the strain gauges is to be adjusted to the upper end of the planned range. At this point, the strain gauges are equalized. After this, the temperature is dropped in steps or continuously and the strain gauge reading is recorded as a function of temperature. The measurement points must be dense enough so that the curve variation is uniquely determined. The temperature change rate is to be selected so that there is heat equalization and so that a drift caused by material conversion or oxidation is avoided if possible, especially in the upper temperature ranges.

3.10.4. Evaluation

a) The k factor determined in Section 3.1 is used to recalculate the measured value using the relationship

$$\epsilon_{\vartheta}^{*} = \frac{\Delta R/R_0}{k}\bigg| \qquad (10)$$

into strain values (10^{-6} m/m). Then a diagram is plotted with the strain as the ordinate and the temperature as the abscissa. The curves may have to be displaced parallel so that they pass through the origin at room temperature or at another convenient reference temperature.

b) The arithmatic mean and standard deviations are formed from the values of all strain gauges corresponding to the same temperature. If the measurement points are randomly distributed with respect to the abscissa, then auxiliary curves are passed through the measured points for the individual strain gauges, so that their variation is used to determine the average value and the standard deviation for certain temperatures. The average temperature variation curve is drawn through the average values.

c) In order to give a better presentation of the results, an appropriate line is drawn through the average temperature variation curve. The inclination of the line is the temperature coefficient of the strain gauge type on the sample plate material. The deviation of the average temperature variation from the line is the nonlinear part of the temperature variation. Both must be calculated. Under some conditions, it is appropriate to draw various lines for various temperature ranges. The rest of the /19 evaluation and presentation can be done separately for each range. For strain gauges with adapted temperature compensation, it is useful to select the abscissa as a reference line.

3.10.5. Representation and Publication

The temperature variation of the strain gauge is to be supplied in the package in the following way:

The nonlinear part of the temperature variation is plotted in a diagram. The ordinate scale is $20 \cdot 10^{-6}$ m/m per cm, the bascissa scale is 20° C/cm for a temperature range $\leq$300° C, 50° C per cm for a temperature range > 300° C.

The linear part is clearly visible in such a diagram in 10^{-6} m/m per degree C in the form of a numerical value.

In addition, the standard deviations from the abscissa upwards and downwards are to be plotted according to Section 3.10.4b. This results in a tolerance band of the temperature variation in which the scatter of the linear part is contained (see, for example, Figure 20).

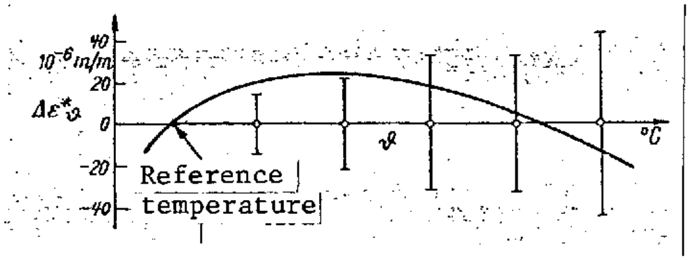

Figure 20. Representation of the temperature variation and its standard deviation.

Special indications:

— sample plate material (DIN or VDEh notation)

— exact value of the heat expansion coefficient of the sample plate material determined in the dialtometer within the temperature range of the diagram. It is desirable to also give deviations of the heat expansion curve from the line described by this coefficient within the temperature range. This is given in a diagram without the scatter.

— it is permissible to color code the strain gauges to avoid confusion by the user. The colors given in Column 2 of Table II are to be used.

3.11. Thermal Hysteresis

3.11.1. Definition

The thermal hysteresis $\epsilon^*_{H\vartheta}|$ is the difference in the measured value for the same temperature which result for increasing and decreasing temperature under otherwise the same conditions.

Remarks: The thermal hystersis is based on complicated processes inside the application material. In addition to true hysteresis, which is caused by measurement grid, carrier, and adhesive materials, processes related to creep and drift are involved, and their influences on thermal hysteresis cannot be eliminated. There is a dependence on the temperature magnitude and its duration, the number of temperature cycles and their variation. Also, there is an influence of the heat expansion coefficient differences between the component and the strain gauge materials, which can produce considerable heat stresses.

3.11.2. Measurement Installation

The measurement installation discussed in Section 3.10.2 is used.

3.11.3. Measurement Method

a) The measurement is done only after previous agreement using a sample selected according to Section 1.6. It can be carried out together with the temperature variation measurement discussed in Section 3.10. .

b) The measurement sequence should be adapted to the applications of a strain gauge. This is especially true for the selection of the sample plate material and the maximum temperature.

c) See Section 3.10.3b to f.

d) The strain gauges are to be equalized at room temperature or at a reference temperature specified by the application.

e) After this, the temperature is increased to its maximum value and then dropped down again to the room temperature or reference temperature.

During the complete cycle, the relative resistance change of the strain gauge is recorded as a function of temperature or this is done in sufficiently close time intervals.

Remark: The temperature change rate should be selected so that the heat exchange requirement within the sample plate is satisfied and so that additional influences are avoided, such as drift because of material conversion and oxidation of the measurement grid material.

f) After this, a similar second temperature cycle is repeated. Measurements with the strain gauges are not required.

g) Sections d and e are repeated (third temperature cycle).

3.11.4. Evaluation

a) For each tested strain gauge, one determines the greatest algebraic difference $\Delta(\Delta R/R_0)|$ between the measured values $\Delta R/R_0|$ of the decreasing and increasing temperature leg at the same temperature, separately for the first and third temperature cycle.

$$\Delta(\Delta R/R_0) = \Delta R/R_0 - \Delta R/R_0. \Big| \qquad (20)$$

b) The arithmetic mean is formed for each temperature cycle from the individual values of the random sample and its standard deviation is determined according to Section 1.6d.

c) The average values are recalculated into strain values (10^{-6} m/m), according to Equation (19) and using the k factor determined in Section 3.1.

3.11.5. Representation and Publication /20

The thermal hysteresis and its standard deviation are given in numerical form.

Special data:

— temperature range

— the average heating time and the time-temperature function

— the sample plate material.

3.12. Temperature Resistance

3.12.1. Definition

According to the directives of this guideline, all important properties of the strain gauges are to be specified as a function of temperature. Thereby, the user is in a position of estimating the permissible temperature limit upwards and downwards which apply for his measurements.

However, it is possible that a strain gauge measurement point is subjected to a temperature before the beginning of the measurement itself which exceeds these limiting values, whereas the measurement will occur in the permissible temperature range. The question is then raised as to whether the important strain gauge properties have been changed or not because the limiting value has been exceeded. It can be assumed that only very high temperatures will lead to permanent changes in the strain gauge characteristics, as a function of the duration. The temperature resistance of a strain gauge or of an application can therefore only be evaluated by determining the extent and nature of changes in such parameters, which are important for the measurement

TABLE III. MINIMUM REQUIREMENTS FOR TESTING OF STRAIN GAUGE CHARACTERISTIC PARAMETERS AFTER THERMAL OVERLOADS

1	2
Characteristic	Specification and representation of changes determined
k factor at room temperature	In % of initial value
Maximum strain at room temperature (3.4)*	Given numerically in 10^{-3} or 10^{-2} m/m
Creep (3.20), but only at room temperature	As a creep curve
Temperature variation (3.10)	As a temperature variation curve
Thermal hysteresis (3.11)	As numerical value in 10^{-6} m/m

* The numbers in parentheses refer to the sections of this paper.

under consideration. For this purpose, it is necessary to again determine them after the expected temperature violation has taken place. The quantities given in Column 1 of Table III are important, in general.

3.12.2. Measurement Installation

The k factor change is determined according to the equipment discussed in Section 3.14.

The installations described in the appropriate sections are used to determine the other characteristics.

3.12.3. Measurement Method

A test is only done after an agreement has been reached and is done under the required temperature and duration conditions. The results of the tests are to include as a minimum the data given in Table III.

The measurements should be carried out for each of the strain gauge types in question. A random sample is taken according to Section 1.6.

The change in the k factor is determined by comparison measurements before and after the heating. The initial measurement is done according to the requirements given in Section 3.14.3a to e. After this, the measurement installation is brought to the increased temperature and is held there for the entire effective time. After cooling down to room temperature, the measurements given in Section 3.14.3e are repeated.

The other parameters given in Table 3 are determined according to the requirements given in each of the sections.

3.12.4. Evaluation

The evaluation directives given in each of the sections apply.

For the k factor, the change in percent referred to the initial value is to be calculated: $(\Delta k/k) 100\%$.

3.12.5. Representation and Publication

The results of the test are presented according to Column 2 of Table III. The directives for the diagrams given in previous sections apply.

Special data:

— magnitude of temperature load and duration of application

— material of the sample plate for temperature determination.

The way in which the results are presented to the user is arbitrary.

3.13. Thermostresses between the Measurement Grid, Connection Materials, and Lead Materials

3.13.1. Definition

If the temperature distribution at the component surface is inhomogeneous where the strain gauge is located, then there will be temperature differences between the contact points of the strain gauge which depend on their position. They can produce thermostresses which depend on the materials in contact and the contact temperatures. The total thermostresses U_{th} which are produced at the leads can lead to considerable measurement errors without special measures.

As an example, we show a strain gauge with different measurement grid parts M_1 and M_2, connections A and leads Z for temperature compensation, Figure 21.

In order to be able to determine the contact point temperatures for given temperature gradient and given position of the strain gauge axes, in particular the temperature differences between the corresponding contact points, it is necessary to know the distance between the contacts in the direction of the measurement strip axes. In the present example, these are the distances h_1 to h_4 (see Section 2.4.2). When there is one and the same measurement wire, only the distances h_1 and h_4 appear. /21

The total thermostress for the strain gauge shown is found to be:

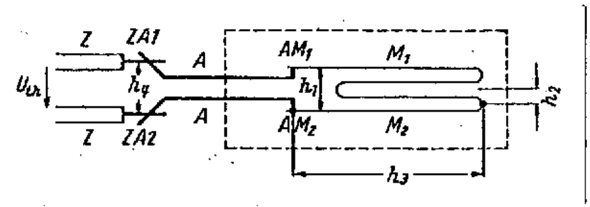

Figure 21. Measurements of the contact points in the strain gauge acting as thermal pairs.

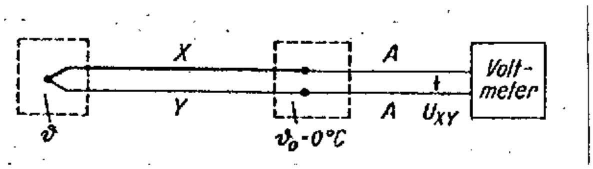

Figure 22. Circuit diagram for determining polarity of a thermo-element.

$$U_{th} = U_{ZA}(\vartheta_{ZA1}) + U_{AM_1}(\vartheta_{AM_1}) - U_{AM_2}(\vartheta_{AM_2}) - U_{ZA}(\vartheta_{ZA2}) - U_{AM_1}(\vartheta_{M_1M_2}) + U_{AM_2}(\vartheta_{M_1M_2}). \tag{21}$$

Here (ϑ)/ is the thermostress of the thermopair X, Y with one contact point at temperature ϑ/ and the second one at the comparison point temperature 0° C, and the polarity is specified according to Figure 22.

In general, the thermostresses of all conductor materials in contact and the individual contact point temperatures must be known. (One of the contact combinations which do not appear in pairs can be found from the others. In the example, we have considered $U_{M_1M_2} = U_{M_1A} + U_{AM_2}$.)

If, in the given temperature range, the thermostresses U_{XY} vary linearly with temperature, only the differential thermostress coefficient

$$\left.\frac{dU_{XY}}{d\vartheta}\right|$$

is important in this range, as well as the temperature difference between corresponding contact points.

3.13.2. Measurement Installation

a) No special measurement equipment is required to determine the mutual distances of corresponding contact points.

b) For determining the thermostresses, two temperature instruments are required which make it possible to maintain temperatures of 0° C and 100° C, respectively, with an error of less than 1° K.

c) The error in the electrical measurement installation cannot exceed ±20μ V or ±1% of the appropriate value. The input resistance should be ≧1 MΩ and the conductor resistance of the thermopair is allowed to go as high as 1 kΩ.

3.13.3. Measurement Method

a) If the mutual separations of corresponding contact points are given during the manufacturing process, then the tolerances given in Section 2.4.2 for the measurement grid dimensions are to be maintained. If the contact points are only produced during the installation, the distances are determined if the user wishes this.

b) The thermostresses are to be determined for each contact combination which occurs in the strain gauge. The contact combinations for which the thermostresses can be determined from the others do not have to be measured. For this test, copper wire having a diameter of 0.5 mm corresponding to the DIN standard 43710 is to be used unless the strain gauge manufacturer uses another material (for example, high temperature strain gauges). Usually, the lead material can be selected by the user. Additional tests of the lead material are optional.

c) The test is to be carried out for the strain gauge family characterized by certain grid and connection materials.

For this purpose, a conductor material is selected as a random sample from a manufacturing lot for each of the contact combinations, according to Section 1.6. The conductor lengths are to be adapted to the measurement installation according to Section 3.13.2.

d) The conductors X and Y of each pair to be investigated are to be connected at the end just like in the strain gauge. This contact point is installed in the temperature installation for 100° C. The two other ends are, for example, to be connected with arbitrarily selectable but identical lines A. These contact points are installed in the tempering installation for 0° C. The thermostresses are measured at the ends of the leads A. Figure 22 shows the circuit. The same material as in Section d of this section is used as a lead material so as to give an accurate and uniform simulation of the strain gauge leads.

e) The thermostresses are to be measured for $\vartheta = 100°C$.

3.13.4. Evaluation

a) The thermostress coefficients for 0 to 100° C are to be measured from the measured thermostress values

$$\left.\frac{U_{XY}}{100} \text{ in } \mu V/K\right| \qquad (22)$$

The average value is formed and the standard deviation is determined.

b) In some cases, the systematic errors caused, for example, by large conductor resistance of the thermoelement, must be corrected. /22

3.13.5. Representation and Publication

a) The distances between contact points in the direction of the strain gauge axes, which are a result of the manufacturing process, are given in numerical form, together with their tolerances. They are explained with a sketch and are published with the other measurement grid dimensions, according to Section 2.4.2 in the form of data sheets or similar documents.

b) The average values of the thermostress coefficients are to be specified for 0 to 100° C for all contact combinations in numerical form with their standard deviations.

3.14. Temperature Dependence of the k Factor (Static)

3.14.1. Definition

The strain sensitivity of a strain gauge which is determined at room temperature according to Section 3.1 depends on temperature:

$$k = \frac{\Delta R/R_0}{\epsilon} = f(\vartheta) \tag{23}$$

This temperature dependence of the k factor is, first of all, a property of the measurement grid material. At increased temperature, there can be a strong decrease in the sensitivity because of softening of the carrier and the adhesive.

3.14.2. Measurement Installation

a) By prescriping the path within three seconds, a special device is used to produce a strain of $\pm(1000 \pm 100) \cdot 10^{-6}$ m/m. The non-uniformity of the strain in the spring carrying the strain gauge must be less than ±2% of the average value. The error in reproducing this cannot exceed $\pm 5 \cdot 10^{-6}$ m/m. A preload is applied for certain zero point adjustment. The prestress of the strain gauge should be at least $20 \cdot 10^{-6}$ m/m and $100 \cdot 10^{-6}$ m/m at the most.

Devices having a bending spring with equal strain (triangle bending strain) which are clamped on one side seem to be suitable for this. Figure 23 shows this. As examples, we have NAS 942 in Section 4.4.10 and ASTM standard E 251-64 T in Section 10.

In contradiction with the NAS version, the thickness of the spring should be at least 6 mm so that scatter in the layer thickness between the measurement grid of the strain gauge and the surface of the bending spring do not have too strong an effect (corresponding to dimension e in Section 3.1.4).

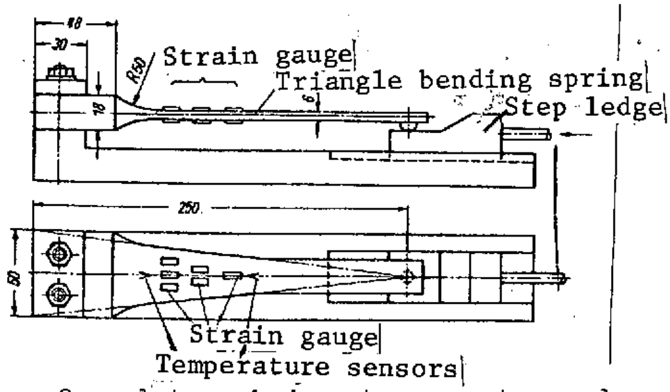

Figure 23. Device for determining temperature dependence of a k factor (schematic).

The bending spring material is determined according to the temperature range in which the device is to be used. We suggest the following:

for temperatures	Material
up to 200° C	Spring steel
200 to 400° C	Heat resistant steel
> 400° C	Highly heat resistant alloys, for example, Nimonic 10.

A temperature sensor is installed at the front and rear edge of the part of the bending spring holding the strain gauge.

b) A tempering chamber for accepting the device in subsection a must be capable of providing uniform heating and cooling down to the limiting temperature values used for testing the strain gauge. Also, it must be possible to operate the device without disturbing the temperature equilibrium. The climate conditions given in Section 1.5.5 are applicable.

c) The electrical measurement installation for determining the relative resistance change $\Delta R/R_0$ of the strain gauge must correspond to the requirements of Section 1.5.1.

d) In order to determine the bending spring temperature, it is necessary to have temperature sensors and a measurement installation already mentioned in subsection a and Section 1.5.2.

3.14.3. Measurement Methods

a) The test is to be carried out for each strain gauge family with one strain gauge type according to Section 1.4b. For this purpose, a random sample is taken from a manufacturing lot according to Section 1.6c.

b) See Section 3.1.3b.

c) The strain gauges are preloaded three times at the strain $(1000 \pm 100) \cdot 10^{-6}$ m/m and are then unloaded again. One half of the random sample experiences only positive deformations and the other half only negative deformations, corresponding to the loading direction during the measurements.

d) The device is placed in the tempering chamber and the strain gauges are connected to the measurement device. The zero points are equalized and the reference values are noted.

The temperature sensors are connected with the temperature measurement device and the readings are recorded.

e) The bending spring is completely deflected within 3 seconds for the initial measurement at room temperature, so that the strain gauge is deformed according to subsection c and the relative resistance change of the strain gauge is measured for an additional 10 seconds.

After this, the bending spring is unloaded within three seconds down to the initial state and the zero point of the strain gauge is determined in an additional ten seconds. (The time limitation is intended to exclude creep errors.)

If the measurement installation is not sufficient for measuring all of the strain gauges of the random sample within the mentioned time interval, then the bending spring must be immediately unloaded and after waiting one minute, the cycle for measuring the next strain gauge is repeated, and so on, until all of the strain gauges have been measured.

This measurement at room temperature results in the value of k = 100%. The numerical value determined according to Section 3.1 of the k factor is not used here (see Section 3.14.4).

f) The temperature of the tempering chamber is brought to the next stage and Section 1.5.5 is taken into account. The temperature steps correspond to the extreme values specified for measurements by the manufacture.

The following steps apply:

Working range of strain gauge	Temperature steps
-80 to +120° C	25° C
-270* to +320° C	50° C
-270* to +1000° C	100° C

*For low temperature ranges which cannot be covered with cryostats or are difficult to produce with them, the properties of liquefied gases should be used [16].

The actual value of temperature can deviate from the nominal value by 10% of the difference between room temperature and nominal temperature. It is to be measured according to the accuracy requirements given in Section 1.5.2.

g) At each temperature stage, the measurement procedure discussed in section e is repeated. It is necessary to make sure that the temperature of the bending spring is equalized to within ≤1% of the difference with respect to room temperature before the measurement is started.

3.14.4. Evaluation

When the lead resistance depends on temperature, then the measured values of Equation (10) must be corrected. For each strain gauge, the deviation of the measured value $|\Delta R_\vartheta/R_\vartheta|$ from the value obtained at room temperature $|\Delta R_{RT}/R_{RT}|$ is to be determined, separately for each strain gauge, and this is divided by the measured value at room temperature:

$$\frac{\Delta k}{k_{RT}} = \frac{(\Delta R/R)_\vartheta - (\Delta R/R)_{RT}}{(\Delta R/R)_{RT}} \, 100\,\% \qquad (24)$$

This relative k factor change is to be plotted as a function of temperature for each strain gauge. At the temperature stages according to Section 3.14.3f, the average values and standard deviations are calculated according to Section 1.6d.

3.14.5. Presentation and Publication

The temperature dependence of the k factor and its standard deviation are plotted in diagrams, Figure 24.

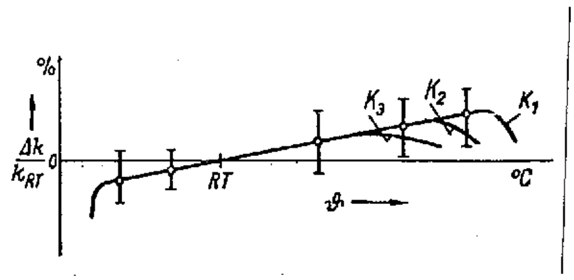

Figure 24. Diagram example for representation of temperature dependence of k factor.

Ordinate scale 10 mm per percent,

Abscissa scale:

20° C per cm up to a maximum temperature of ≦320° C,

50° C per cm for a maximum temperature of > 320° C.

If a strain gauge is tested with several adhesives, then it is necessary to present the results in different diagrams. The publication is done in the form of technical data sheets or by a similar method.

3.15. Maximum Strain Capacity as a Function of Temperature

3.15.1. Definition

The definition given in Section 3.4.1 applies. The maximum strain capacity is temperature dependent because of the compression stresses caused by the restriction of heat expansion.

3.15.2. Measurement Installation

In addition to the instruments discussed in Section 3.4.2a to c, the following are required:

d) A thermostat, which satisfies the requirements of Section 1.5.5 and with which the temperature can be adjusted to ±2° K or ±2% of the reading in degrees Celsius. Also, a uniform heating of the load device and of the bending beam must be provided for. The load device must be operable without influencing the temperature equilibrium.

The comparison strain measurement device according to Section 3.4.2b must be suitable for the planned temperature and must be calibrated. Its error tolerance is increased by $\pm 25 \cdot 10^{-6}$ m/m or 1% of the strain for each 50° C difference with respect to the room temperature.

e) A temperature measurement installation according to Section 1.5.2.

3.15.3. Measurement Methods

The measurement procedure discussed in Section 3.4.3a to d is used with the following additions:

a) The test is done after a special agreement has been reached. It is carried out at a temperature for which the strain gauge will be used. The tests at other temperatures are optional.

d) Before loading the bending beam, it is heated to the planned temperature and temperature equalization occurs.

3.15.4. Evaluation /24

The evaluation is done according to Section 3.4.4 with the following differences:

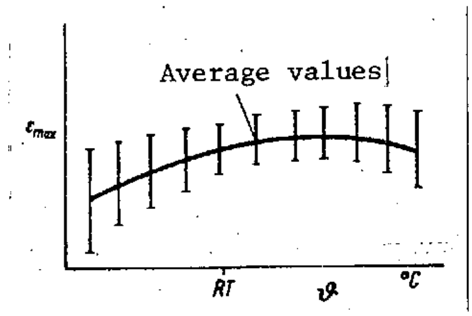

Figure 25. Diagram example for representation of maximum strain as a function of temperature.

Strain readings of the strain gauge is calculated from the relative resistance change and from the k factor corrected for the test temperature as discussed in Section 3.4. The k factor was determined according to Section 3.1.

3.15.5. Presentation and Publication

The measurements results are presented according to Section 3.4.5. If several temperatures are measured, then the maximum strain capacity is to be presented as a function of temperature. The ordinate scale should be $2 \cdot 10^{-3}$ m/m or $20 \cdot 10^{-3}$ m/m per cm; the abscissa scale is selected according to Section 3.4.5, Figure 25.

In the case where the maximum strain capacity is greater than the working range of the measurement device, then the nomogram given in Figure 12 of Section 3.4.5 is drawn for each temperature.

3.16. Maximum Strain Capacity as a Function of Humidity at Room Temperature

3.16.1. Definition

The definition given in Section 3.4.1 applies. The dependence of the maximum strain capacity on relative humidity of the surrounding air is given. The humidity absorbed or given off by the strain gauge carrier or the adhesive is related to a volume change. The resulting strain is prevented by the component. In this way, force stresses occur which can lead to a premature failure of the application.

Remark: The influence of the maximum strain capacity is greater when the strain gauge has been stored and mounted under very dry or very wet climate conditions [21].

3.16.2. Measurement Installation

In addition to the devices mentioned in Section 3.4.2, a climate chamber which can accept the test device is required. With it, it must be possible to set a relative air humidity between 20% and 80% to within ±2% and it must be maintained to within ±2%.

The operation of the comparison strain measurement device cannot be influenced by humidity.

3.16.3. Measurement Methods

The method discussed in Section 3.4.3a to d is to be used with the following additions:

a) The test is only done after an agreement has been reached. The relative humidity at which measurements are performed is agreed to. The relative humidity values of 20%, 30%, 50%, 70%, and 80% are preferred.

Remarks: The value for 50% relative humidity is already discussed in Section 3.4.

d) Before the load is applied, the desired humidity level is produced in the climate chamber and maintained for 72 hours.

3.16.4. Evaluation

It is evaluated according to Section 3.4.4.

3.16.5. Presentation and Publication

If measurements are carried out with a single level of humidity, then the result is presented according to Section 3.4.5. If measurements are performed at various humdities, then the average values and standard deviations for $\epsilon_{max}|$ are presented as functions of relative humidity. The ordinate scale is $2 \cdot 10^{-3}$ m/m per cm or $20 \cdot 10^{-3}$ m/m per cm. The abscissa scale should be 10% of relative humidity per cm.

If the maximum strain capacity is greater than the working range of the measurement installation, then the nomogram given in Figure 12 of Section 3.4.5 is drawn for each humidity value.

3.17. Heat Shock Behavior

The heat shock behavior comes about by the complex interaction of various properties of the strain gauge, for example temperature variation, thermal hysteresis, and cooling rate.

In spite of its importance for special applications, the treatment of the heat shock behavior is deferred because a satisfactory testing method is not yet known.

3.18. Drift as a Function of Temperature

3.18.1. Definition

The thermal drift is produced primarily by matrix changes and oxidation or corrosion of the measurement grid material or by stress-unloading processes in the strain gauge or adhesive because of prolonged effects of heat. It depends on temperature and time. The thermal drift is characterized by non-reversible zero point changes of the applied strain gauges. Reversible changes, for example the temperature variation (see Section 3.10), or other influences, for example humidity (see Section 3.21), are not part of the thermal drift.

In this guideline, by thermal drift, we mean the zero point change of an applied strain gauge which is exposed to a constant temperature according to the conditions of Section 3.18.3.

3.18.2. Measurement Installation

The measurement installation for determining the resistance change and temperature, the measurement point switch and the sample plates for accepting the strain gauges should satisfy the requirements of Section 3.10.2. Recording devices, such as linear recorders, point printers, numerical printers, etc., must be able to reproduce the curves with sufficient resolution for measurement durations up to 24 hours.

The tempering installation should allow an average temperature increase of the sample of 0.25 K/sec. The tolerance on the actual temperature is the greater of the quantities ±10° K or 5% of the nominal temperature. During the duration of the test, the temperature must be maintained constant to within ±1%.

3.18.3. Measurement Methods

a) The measurement is done according to Section 1.4b on a strain gauge type with a measurement grid length of 6 mm. The results apply for the entire strain gauge family. For the test, a random sample of at least five strain gauges are used.

b) See Section 3.10.3b. For sample plates, one selects the same material as was used for determining the temperature variation, Section 3.10.

c) See Section 3.10.3c.

d) See Section 3.10.3d.

e) See Section 3.10.3e.

f) See Section 3.10.3f.

g) The sample plate is heated at a heating rate of 0.25 K/s up to the test temperature. The test temperature is maintained constant during the measurement, to within ±1%. Deviations of the actual temperature from the nominal temperature up to ±10° K or 5% are permissible at all temperature stages.

h) Just after the test temperature is reached, the readings of the strain gauges are recorded. In the case of continuous recording, this point on the curve is marked.

Twenty-four hours represents the measurement duration, unless the lifetime of the strain gauge or its practical lifetime are exceeded (for example, in the high temperature range).

i) The lowest temperature at which measurements are carried out is specified as 100° C. The highest temperature for drift measurements is the value which was determined to be the limiting value for use of the strain gauges according to tests carried out according to Sections 3.14, 3.10, 3.11, and 3.17. Also, the corresponding adhesive must be appropriate for the static measurements.

The highest temperature is specified by the manufacturer. The intermediate temperatures are structured as follows:

Highest temperature	Temperature step
to 300° C	100° K
to 550° C	150° K
to 900° C and above	200° K

The last measurement is to be carried out for the highest temperature indicated for static measurements.

k) Sections g and h are repeated at the next highest temperature step, until the highest temperature is reached.

3.18.4. Evaluation

a) The average values and standard deviations are determined from the measurement series at each temperature level.

b) Using the k factor determined in Section 3.1, the average values and standard deviations are converted to "strain value" (10^{-6} m/m).

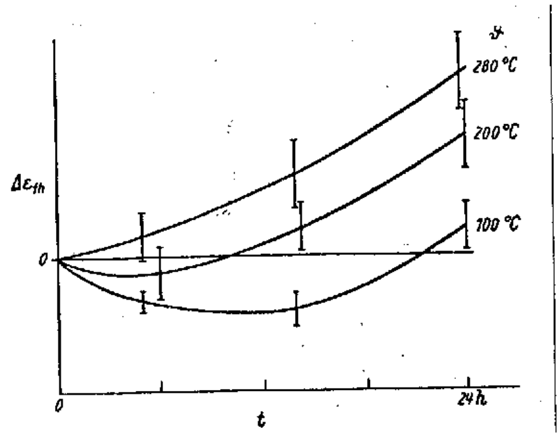

Figure 26. Example for representation of zero point drift as a function of time with the temperature as a parameter.

3.18.5. Presentation and Publication

The results of the drift measurement are published in the form of data sheets.

A diagram is drawn according to values calculated in Section 3.18.4b.

Curves are drawn for each temperature step from the average values. The standard deviations are indicated. The lowest temperature which occurred during the measurements is the parameter. Figure 26 shows an example.

Special data:

The linear heat expansion coefficient of the sample plate material is specified.

3.19. Continuous Oscillation Behavior at Room Temperature

3.19.1. Definition

If a strain gauge is loaded with a sinusoidal alternating strain having amplitude $|\hat{\epsilon}|$, which can be superimposed on a static average strain ϵ_m, changes in the strain gauge measurement values with respect to the zero point and with respect to the average strain can occur as the number of load cycles N is increased. Also, irregularities in the resistance-strain characteristic can be produced. In general, the k·factor remains constant. In special cases, changes can occur. These effects are summarized as "continuous oscillation behavior of strain gauges" [17]. They /26
depend on the alternating strain amplitude and average strain but are mostly independent of frequency. They are primarily due to changes in the measurement grid and in the connections, caused by the changing load.

3.19.2. Measurement Installation

A suitable device is used to produce a sinusoidal strain with a constant amplitude. It has to be adjustable between zero and $2 \cdot 10^{-3}$ m/m to within $\pm 25 \cdot 10^{-6}$ m/m or 5% of the value. It must have at least the steps $0.5 \cdot 10^{-3}$ m/m, $1 \cdot 10^{-3}$ m/m, $1.5 \cdot 10^{-3}$ m/m and $2 \cdot 10^{-3}$ m/m. The frequency of the alternating strain cannot exceed 50 Hz. Load cycle numbers between N = 1 and 10^6, or even better, 10^7, must be capable of being indicated.

If a static average strain is required, then the bending spring according to Figure 27 is used for this. The strain gauges are applied in this state. The average strain must be adjustable between 0 and $\pm 4 \cdot 10^{-3}$ m/m to within $\pm 50 \cdot 10^{-6}$ m/m

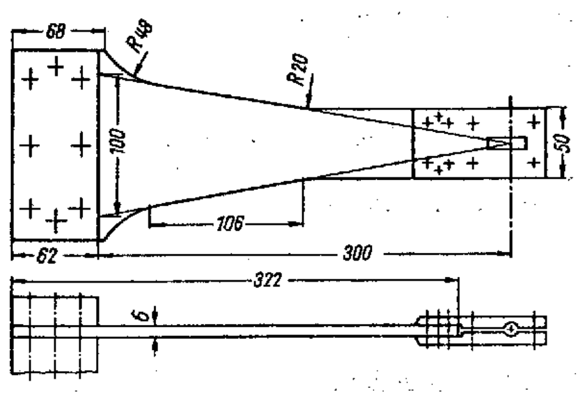

Figure 27. Bending spring for measuring continuous oscillation behavior of the strain gauge.

or ±5% of the value. It must have at least these steps 0, $\pm 1 \cdot 10^{-3}$ m/m, $\pm 2 \cdot 10^{-3}$ m/m, and $\pm 4 \cdot 10^{-3}$ m/m. In the useful interval of the bending spring, Figure 27, the strain must be constant to within ±5% of its average value. The strains adjusted for measuring the change in the zero point or the static average strain (close to the zero spring strain) must be reproducible to within $\pm 2 \cdot 10^{-6}$ m/m. The strain differences adjusted for measuring the sensitivity changes (about twice the amplitude) must be reproducible to within $\pm 2 \cdot 10^{-6}$ m/m or ±0.5% of the strain difference. The strain adjustments can be done statically using a clamping screw and can be measured with a caliper after previous calibration.

Testing devices which have proven themselves are a triangular bending spring clamped on one side with a constant strain in the useful range, as well as an eccentric drive with a special form for providing a constant strain amplitude. As an example, we can mention the alternating bending machine of the BAM, which was built according to the machine described in [1], [17]. The shape of the spring is shown in Figure 27. Titanium alloy TiA 16 V 4 is suitable as a material.

The electrical measurement installation for static measurement of the resistance change $\Delta R/R_0$ of the strain gauge must satisfy the requirements of Section 1.5.1.

The devices for observing the oscillation image for determining irregularities in the resistance-strain characteristic, such as a dynamic strain measurement bridge with subsequent cathode ray oscillograph, must be capable of detecting irregularities in the strain-time variation or in the resistance-strain variation of at least ±2% of the existing strain amplitude.

3.19.3. Measurement Method

The test is carried out after special agreement has been reached for each strain gauge family using one type according to Section 1.4b. A random sample is taken from a manufactured lot according to Section 1.6 and the tests are carried out for the static average strain zero and the alternating strain amplitudes $2 \cdot 10^{-3}$ m/m, $1.5 \cdot 10^{-3}$ m/m, $1 \cdot 10^{-3}$ m/m, and $0.5 \cdot 10^{-3}$ m/m.

If agreed, the results are to be tested using two samples from the same manufactured lot, as regards the static average strain + and $-1 \cdot 10^{-3}$ m/m, + and $-2 \cdot 10^{-3}$ m/m, as well as + and $-4 \cdot 10^{-3}$ m/m.

If the changes in the zero point and/or the average strain are within $\pm 10 \cdot 10^{-6}$ m/m, the changes in sensitivity within ±1% and the irregularities in the resistance-strain characteristic are within ±2% of the alternating strain amplitude, then no measurements have to be carried out at smaller alternating strain amplitudes and average strains. (If the results of one strain gauge family are to be transferred to another with the same grid material and lead material, but a different adhesive and carrier material, then under some conditions a testing of the results using two samples per alternating strain amplitude and possibly one sample per static average strain will be sufficient. Each change in the grid or lead material makes it necessary to carry out a test and, in general, a new determination of the long duration oscillation behavior.)

The strain gauges are to be stored according to conditions of Section 1.5.6, and are applied according to Sections 2.5 and 2.6 onto the bending spring, and possibly, onto the spring which has the negative average strain. The adhesion conditions must be uniform for all strain gauges. The measurements are carried out under normal climate conditions according to Section 1.5.4.

If it is necessary to unload the deflected spring, three load cycles are applied with the previously adjusted strain amplitude. After this, the reference values are determined for the zero point of the spring, the zero point, and the average strain. Additional measurements are used to determine the upper and lower dead point of the eccentric member. Also, the strain gauge sensitivity is determined.

After equal logarithmic separations, at least after 10, 30, 100, 300, ..., to 10^6, and better, 10^7, load changes, one determines the changes in the zero point, average strain, and sensitivity, according to the previous section. /27

The oscillation image is observed and irregularities >±2% of the strain amplitude are noted at shorter and logarithmically equidistant separations, at least after 10, 18, 30, 60, 100, 180, 300, ... load changes, in order to test the irregularities in the resistance-strain characteristic of the strain gauge. This test also determines the production of permanent fractures, when they are still loosely held together.

3.19.4. Evaluation

a) The k factor changes are determined for each individual strain gauge according to

$$\frac{\Delta k}{k} = \frac{k_N - k_{N=3}}{k_{N=3}} = \left| \frac{\left|\frac{\Delta R}{R_0}{}_{\text{pos N}}\right| + \left|\frac{\Delta R}{R_0}{}_{\text{neg N}}\right| - \left[\left|\left(\frac{\Delta R}{R_0}\right)_{\text{pos N = 3}}\right| + \left|\left(\frac{\Delta R}{R_0}\right)_{\text{neg N = 3}}\right|\right]}{\left|\left(\frac{\Delta R}{R_0}\right)_{\text{pos N = 3}}\right| + \left|\left(\frac{\Delta R}{R_0}\right)_{\text{neg N = 3}}\right|} 100\,\% \right| \quad (25)$$

The subscripts "pos" and "neg" refer to the strain of the spring from the zero points after + or -N = 3 load cycles. If deviations between the k factor for positive and negative strains of >0.5% occur, this must be indicated. In order to determine the changes in the zero point and average strain, $\Delta R/R_0$ is measured and is recalculated using the k factor determined in Section 3.1 and the zero point change or average strain is calculated, starting with the reference value for $\epsilon_m = 0$ or = 0 after three load cycles.

$$\Delta\epsilon_m = \frac{\Delta R/R_0}{k} \quad (26)$$

Only in exceptional cases is it possible to separate the changes in the zero point from that of the average strain, in general this is not necessary.

b) The values for Δk/k and $\Delta\epsilon_m$ determined for the individual strain gauges are plotted against the logarithm of the load cycles N and the individual measurement points are connected by lines. The polygon lines are used to determine the load cycle numbers, for which, for the first time, the values

$|\Delta\epsilon_m| = 10 \cdot 10^{-6}$ m/m, $30 \cdot 10^{-6}$ m/m, $100 \cdot 10^{-6}$ m/m, $300 \cdot 10^{-6}$ m/m ... and possibly $|\Delta k/k| = 1\,\%, 2\,\%, 3\,\%, 4\,\% \ldots$

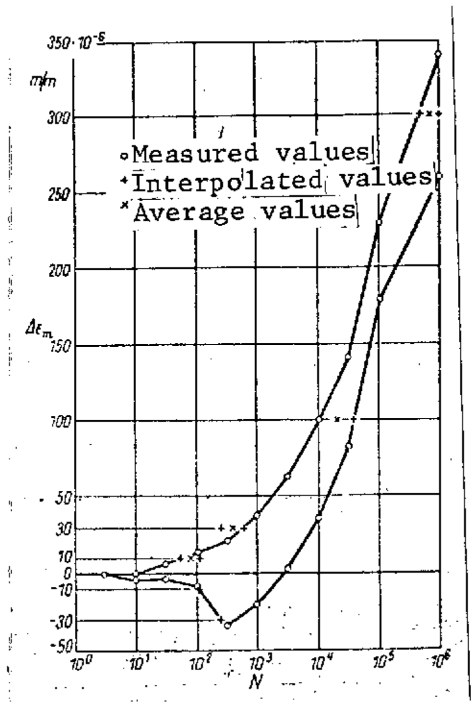

Figure 28. Diagram example for determining zero point changes of strain gauges because of the dynamic loads.

have been exceeded. This is shown in Figure 28 for the change in the average strain of two samples. The geometric average and standard deviation of the logarithms of the load cycle numbers are determined for the load cycle numbers of the various strain gauges. Also, the geometric average values and standard deviations of the logarithms of the load cycle numbers N must be formed after which, for the first time, there has been an irregularity in the resistance-strain characteristic. If the values mentioned above are exceeded for at least one sample and not for the others, then for this one, the values $N = 10^6$ and 10^7 are accepted when determining its average value of the load multiples and its standard deviation.

Remark: The geometric average of the load cycle number N and its standard deviation are obtained by forming the arithmetic mean and standard deviation of the logarithms of the load multiples and we have $\log \bar{x} = \log N$ (and s remains the standard deviation of the logarithms of the load cycle numbers).

3.19.5. Presentation and Publication

The measurements results for the average strain zero are presented in the form of Woehler curves as continuous oscillation diagrams for the zero point changes, for the k factor changes, and for the irregularities above ±2% of the alternating strain amplitude, for example, due to permanent fractures in the measurement grid. The alternating strain amplitude $\hat{\epsilon}|$ is to be plotted as a function of the load cycle number N, after which, according to Section 3.6.4b, the zero point is different by 10, 30, 100, 300, ... $\cdot 10^{-6}$ m/m, the k factor differs by 1, 2, 3, 4, ... %, and the irregularity in the resistance change characteristic are greater than ±2%. The standard deviations of the logarithms of the average values are to be plotted according to Section 3.19.4b.

The results can be plotted on a single diagram, especially when there is no observed sensitivity change, which is often the case. The ordinate scale should be $250 \cdot 10^{-6}$ m/m per cm and the abscissa scale should vary from 1 to 10^6 or 10^7 load cycles per power of ten 2 cm. /28

Figure 29 gives an example of the continuous oscillation diagram and zero point change $\Delta\epsilon_m|$ (average strain zero) and the fracture in the grid.

If the continuous oscillation behavior has been agreed to be measured for various average strains $\neq 0$, then the corresponding continuous oscillation diagrams can be specified for each average strain. It is most important to present the continuous oscillation strains at which the phenomenon has occurred after 10^6 as a function of the static average strain $\epsilon_m|$. This is according to the continuous strain diagrams of Haigh [18].

The ordinate scale should be $250 \cdot 10^{-6}$ m/m per cm and the abscissa scale — $500 \cdot 10^{-6}$ m/m per cm. Figure 30 shows an example of such a diagram.

The results are presented in the form of data sheets.

3.20. Creep as a Function of Temperature

3.20.1. Definition

If a strain gauge is subjected to a static strain then in spite of a constant component strain, there is a change in resistance over time: the strain gauge creeps [19; 20].

If after this the component is unloaded to the strain zero and this state is retained, then there will be a zero point displacement corresponding to the creep (and hysteresis, see Section 3.2) of the strain gauge, which also changes in time. The creep is usually against the direction of the previous strain change. It is essentially caused by the relaxation of the carrier and adhesive because of the restoring force of the measurement grid and depends very greatly on the previous history and surrounding temperature. If the prestresses in the strain gauge can be ignored, it is usually proportional to the strain. The temperature dependence of creep is explained by the temperature dependence of the modulus of elasticity and of relaxation, especially for the plastic components of the strain gauge carrier and of the adhesive in any application.

By the relative creep of strain gauge in the sense of this guideline, we mean the apparent change in the strain gauge measured value $\Delta\epsilon^*|$ referred to the initial value $\epsilon^*_0|$, as a function of time t and temperature $\vartheta|$ after the first load:

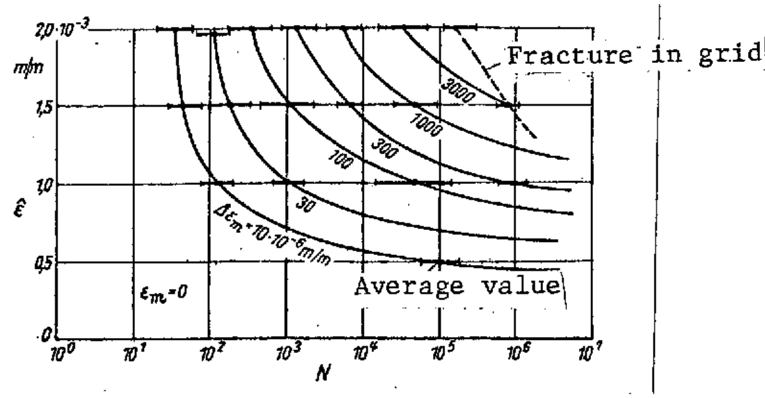

Figure 29. Diagram example for representation of zero point change of dynamically loaded strain gauges as a function of strain amplitude $\hat{\varepsilon}$ and load play N for average strain ε_m = o.

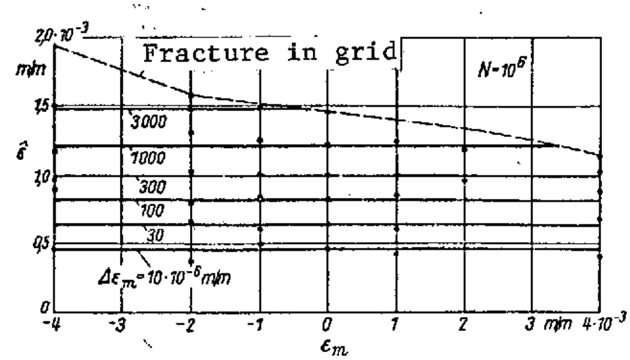

Figure 30. Diagram example for representation of zero point change of dynamically loaded strain gauges as a function of strain amplitude ε and average strain ε_m for certain load play number N.

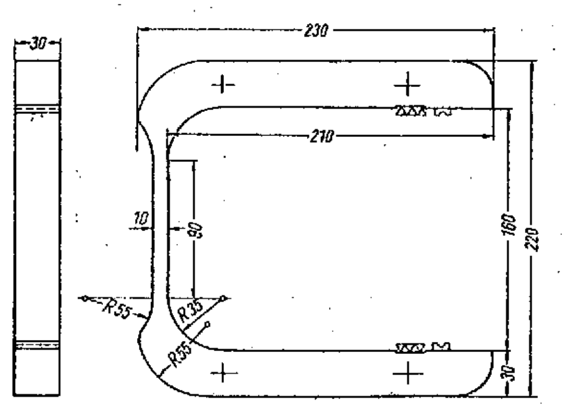

Figure 31. Bending beam for measuring creep.

$$\frac{\Delta\epsilon^*}{\epsilon^*_0} = f(t, \vartheta) \quad (27)$$

3.20.2. Measurement Installation

a) A suitable device is used to provide a strain which is constant in time. It must be adjustable between zero and $\pm 2 \cdot 10^{-3}$ m/m to within $\pm 50 \cdot 10^{-6}$ m/m or ±5%, at least in the steps $+2 \cdot 10^{-3}$ m/m and $-2 \cdot 10^{-3}$ m/m.

Over the length of the useful length of the bending beam, the average value of the strain must be constant to within ±2%. The strain must be constant to within $\pm 2 \cdot 10^{-6}$ m/m over time, at least during the first 24 hours after the change in the load state.

The bending beam shown in Figure 31 is suggested as a test facility with the attachments at both ends. It is used in the same way by BAM for creep measurements. /29

The material RABw steel from Roechling has been found to be useful and is hardened to a strength of 120 kp/mm^2. The bending beam is opened up with a suitable device before the strain gauges are applied. The deformation is reversed for the measurement, until the extensions run up on a bolt having the same length, made of the same material. The strain is made constant over time because it is not the deformation force but the deformation path which is specified and also measurements are carried out after unloading, after which the creep of the beam will be smaller than after loading. If both sides of the bending beam are covered with strain gauges, then the creep measurement can be carried out in a positive and negative deformation range at the same time. In spite of the normal force components in the load of the bending beam, the bending strain values remain within the tolerances mentioned in Section 3.20.3d.

b) The test device is inserted into a thermostatically controlled chamber with a corresponding mechanical and electrical lead, which also satisfies the requirements of Section 1.5.5, and also maintains the prescribed humidity. The temperature is maintained to within ±0.5° K or ±0.5% of the value in degrees Celsius.

c) The electrical measurement installation for measuring the relative resistance change $\Delta R/R_0$ after loading must have a time resolution and be constant over time to within ±2μΩ/Ω or ±2% of the existing value. In addition, the requirements mentioned in Section 1.5.1 must be met.

3.20.3. Measurement Methods

a) The test is carried out after a special agreement has been reached for each strain gauge family using a type according to Section 1.4b. A random sample is taken from a manufactured lot according to Section 1.6 and the measured temperatures are specified according to Section e of this section. Other random samples for creep measurements at the temperature stages found in this way are taken from the same manufactured lot. The tests are carried out with three strain gauges each for positive and negative strain. If systematic differences in the creep of the strain gauges occur for positive and negative strain, then at least five strain gauges must be used in order to provide a sufficient statistical validity of the results for each of the two strain directions.

b) The strain gauges must be stored according to the storage conditions of Section 1.5.6 and are applied according to Sections 2.5 and 2.6 to the (deformed) measurement installation.

c) The strain gauges are subjected to the temperature discussed in Section 1.5.5. This state is maintained for 72 hours.

d) A strain of + and $-(2000 \pm 100) \cdot 10^{-6}$ m/m is applied within ten seconds and the relative resistance change $(\Delta R/R_0)_0|$ is measured. For a constant strain and for 24 hours, the additional relative resistance change $\Delta(\Delta R/R_0)|$ is measured. After this, the strain gauges are excluded from additional investigations.

e) In order to appropriately select the measurement temperatures, the creep of two strain gauges at different temperatures corresponding to b to d are measured at separated by about 20° C but only for one hour. Before each measurement, one must wait for a few hours until the reading changes of the strain gauges is small compared with the last creep value. Starting at a certain "discontinuity temperature," the creep will increase drastically. The creep measurements are carried out at room temperature, at a temperature just below the discontiniuity temperature, and at an intermediate temperature, as well as at a temperature just above the discontinuity temperature and one temperature step above that, except for negative temperatures.

The same strain gauges can be used for measuring at a temperature above the discontinuity temperature, which were already used at a temperature below the discontinuity temperature.

3.20.4. Evaluation

a) The relative creep is determined according to

$$\frac{\Delta\epsilon(t)}{\epsilon_0} = \frac{\Delta(\Delta R/R_0)}{(\Delta R/R_0)_0} \, 100\% \qquad (28)$$

from the relative resistance change $(\Delta R/R_0)_0$ and the additional time change $\Delta(\Delta R/R_0)$ which occur when the strain is applied.

b) The relative creep is plotted as a function of time t for a strain of $\pm 2 \cdot 10^{-3}$ m/m and the various temperatures ϑ are the parameters. The diagram is used to determine the times at which the relative creep exceeds ±0.1%, ±0.2%, ±0.5%, ±1%, ±2%, ±5%, ±10%. Considering the method of representation, the average values and the standard deviations are determined for the logarithms of these times. This may have to be done for the positive and negative strains.

3.20.5. Presentation and Publication

The measurement results are presented in the form of time-temperature creep diagrams (ZTK). The time has a logarithmic scale and the time at which the magnitude of relative creep exceeds the curve parameter values 0.1%, 0.2%, 0.5%, 1%, 2%, 5%, 10% at each temperature are plotted as a function of temperature. The average values and standard deviations of the times are indicated in the diagram.

The time is recorded from 0.01 to 100 hours on a logarithmic scale of one power of ten per 2 cm. The abscissa scale is 10° K per cm or 50° K per cm. Figure 32 gives an example of a ZTK diagram.

The diagrams are published in the form of data sheets or similar documents.

/30

3.21. Drift as a Function of the Relative Humidity at Room Temperature

3.21.1. Definition

If a strain gauge is in an atmosphere with variable relative humidity, then there will be a slow change in the resistance. This phenomenon [19, 21] can be attributed to the prevention of the swelling and shrinking processes which depend on humidity and bring about internal stresses in the carrier. These are at least partially transferred to the measurement grid. On the other hand, installation defects such as corrosion can play a role and depend on the carrier frequency. The time dependence of the effect is partially due to the fact that the humidity penetrates or leaves the carrier only slowly.

3.21.2. Measurement Installation

a) The sample plates according to Section 3.10.2 are used for holding the strain gauges.

b) A suitable device is used to produce the relative humidity of the air at room temperature surrounding the sample plates containing the applied strain gauges. It must lie between 20 and 80% and must be adjustable at least at the steps 20, 50, and 80%, to within ±2% relative humidity and it must be possible to change it within one hour from 50 to 20% or from 50 to 80%. The relative humidity must be constant to within ±2% and the temperature to within ±1° K for at least 72 hours.

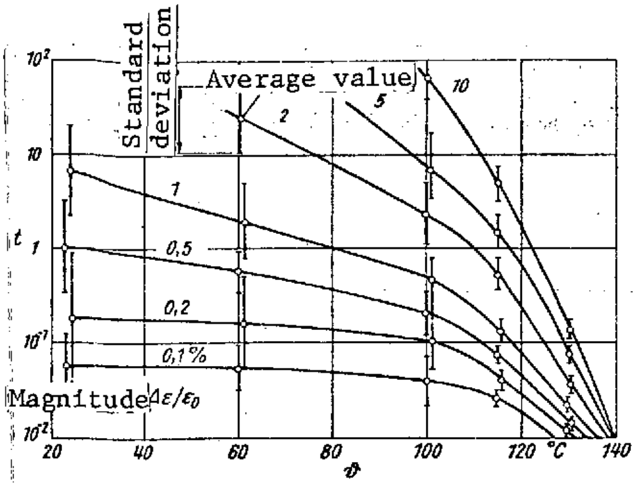

Figure 32. Time-temperature creep (ZTK) diagram.

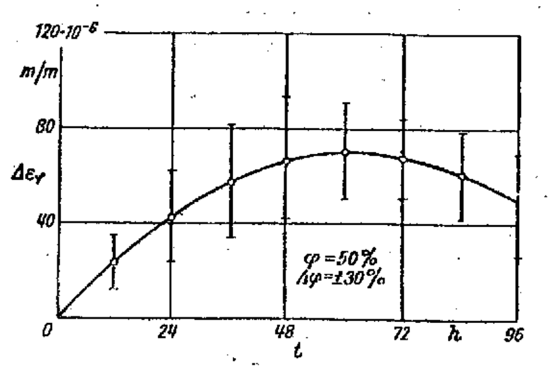

Figure 33. Example for representation of zero point drift as a function of time caused by a jump in humidity.

For example, climatically controlled chambers with a time constant of one hour for humidity changes are suitable for this application.

c) The electrical measurement installation for measuring the relative resistance change $\Delta R/R_0$ must conform with the requirements of Section 1.5.1. The carrier frequency must lie between 100 and 250 Hz for the measurements and the supply voltage can only be connected for, at the most, 1% of the observation time.

3.21.3. Measurement Method

The test is subject to agreement for each strain gauge family using a type according to Section 1.4b. A random sample is taken from a manufactured lot according to Section 1.6. One half of these is used for measurements with positive humidity change and the other half — for negative humidity change.

b) After a previous storage according to Section 1.5.6, the strain gauges are attached to the sample plates according to Sections 2.5 and 2.6. The complete application is stored according to Section 1.5.6 under standardized climatic conditions. The measurement of the reference resistance R_0 is carried out in this state.

c) Within one hour at the most, the relative humidity is changes from (50 ± 2)% to (80 ± 2)% or to (20 ± 2)% and is maintained constant for 72 hours to within ±2%. The relative resistance change $\Delta R/R_0$ is measured as a function of time.

3.21.4. Evaluation

a) The relative resistance changes $\Delta R/R_0$ are used to determine the drift $\Delta\epsilon_\varphi$ in 10^{-6} m/m using the k factor determined in Section 3.1:

$$\Delta\epsilon_\varphi = \frac{\Delta R}{R_0}\frac{1}{k} \tag{29}$$

b) The average value $\overline{\Delta\epsilon_\varphi}$ of the drift $\Delta\epsilon_\varphi$ is determined considering the sign of the humidity change for each strain gauge and the standard deviation is determined.

3.21.5. Presentation and Publication

The results are published in diagram form. The quantity $\Delta\epsilon_\varphi$, considering the sign of the humidity change, is plotted as a function of time. The standard deviation is marked. The ordinate scale should be $20 \cdot 10^{-6}$ m/m per cm and the abscissa scale — 10 hours per cm. Figure 33 shows this zero point drift which results after a jump in relative humidity from 50% by + and -30%.

4. LIST OF NOTATION USED /31

F	force
L	length
L_0	reference length (initial value)
N	load cycle number
P	statistical certainty (confidence region)
R	in statistics: extent of a random sample (range)
$\bar{R}$	in statistics: arithmetic mean of $R_1 \ldots R_n$
R	electrical resistance
R_0	reference resistance (initial value)
R_K	electrical resistance of cables and connection lines
U_a	bridge output voltage (measured signal)
U_e	bridge input voltage (supply voltage)
U_{th}	thermostress
U_{XY}	thermostress of the thermopair X, Y
a	one-half base length of curvature meter
c_{DMS}	spring constant of strain gauge (DMS strain gauge)
d_2	statistical table value
e	distance between bending beam surface and measurement grid of strain gauge
f_l	linearity error
f_l^*	linearity error including sample scatter of k factor
f_{rel}	relative error
h	thickness of bending beam
k	sensitivity constant of strain gauge (k factor)
k_M	strain sensitivity of measurement grid material
k_{Rt}	k factor at room temperature
k_l	strain sensitivity of strain gauge in a uniaxial strain field parallel to measurement direction
k_q	strain sensitivity of strain gauge in a uniaxial strain field perpendicular to measurement direction
k_ϑ	k factor at temperature ϑ
m, n	number
$p_{1,2}$	bending arrow

q	transverse sensitivity of strain gauge (q factor)
$r_{1,2,min}$	radius
s	standard deviation of a measured quantity
t	in statistics: a table value
t	time
$x_1 \ldots x_i \ldots x_n$	measured values
$\bar{x}$	arithmetic mean of $x_1 \ldots x_n$
Δ	arithmetic increment of subsequent quantities
$\Delta\epsilon_{th}$	thermal drift
$\Delta\epsilon_{\varphi}$	drift dependent on humidity
α_B	linear heat expansion coefficient of component material
α_{DMS}	temperature coefficient of a strain gauge
α_M	linear heat expansion coefficient of measurement grid material
α_{Mst}	temperature coefficient of a strain gauge measurement point
α_R	temperature coefficient of electrical resistance
ϵ	strain
ϵ_0	reference value for strain (initial value)
$\epsilon_{1,2}$	principal strain directions
$\epsilon^*_{H\vartheta}$	thermal hysteresis
ϵ_M	strain of strain gauge measurement grid
ϵ_l	strain in the measurement direction of strain gauge
ϵ_{lb}	longitudinal strain of bending beam in Section 3.5.
ϵ_m	average strain (for alternating or swelling load)
ϵ_p	surface strain of a bending beam
ϵ_q	strain perpendicular to measurement direction of strain gauge
ϵ_{qb}	transverse strain of bending beam in Section 3.5.
ϵ^*_{ϑ}	measured value because of temperature influences
$\bar{\epsilon}$	arithmetic mean of $\epsilon_1 \ldots \epsilon_n$
$\hat{\epsilon}$	alternating strain amplitude
ϵ^*	measured value of strain (not corrected)
ϑ	temperature
ϑ_{XY}	temperature at contact point XY
μ	Poisson number
ρ	$\Delta R/(R_0 + R_K)$

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DIN 323	Standard Numbers
DIN 1301	Units, Abbreviations
DIN 1302	Mathematical Symbols
DIN 1304	General Formula Notation
DIN 1319	Fundamentals of Measurement Technology
DIN 1350	Symbols for Strength Calculations; Formula Notation — Mathematical Symbols — Units
DIN 7168	Permissible Deviations for Measurements without Tolerance Indications
DIN 43710	Thermostresses and Materials of Thermopairs
DIN 50014	Material, Component, and Instrument Tests, Normal Climatic Conditions
DIN 50100	Continuous Oscillation Experiment
DIN 55302	Statistical Evaluation Methods; Frequency Distribution, Average Value and Scatter

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